

1557.73
Gr-219
c.3

2221838



STATE OF ILLINOIS

1966

DEPARTMENT OF REGISTRATION AND EDUCATION

CRUSTAL TECTONICS AND PRECAMBRIAN BASEMENT IN NORTHEASTERN ILLINOIS

Lyle D. McGinnis

ILLINOIS DOCUMENTS

ILLINOIS STATE LIBRARY

~~CONNECTICUT~~
~~STATE LIBRARY~~

~~JUL 12 1966~~

~~DISCARDED~~

APR

1966

~~HARTFORD,~~
~~CONNECTICUT~~

CSL

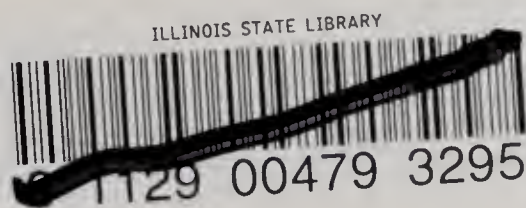
REPORT OF INVESTIGATIONS 219

ILLINOIS STATE GEOLOGICAL SURVEY

URBANA, ILLINOIS

CRUSTAL TECTONICS AND PRECAMBRIAN BASEMENT IN NORTHEASTERN ILLINOIS

Lyle D. McGinnis



STATE OF ILLINOIS

DEPARTMENT OF REGISTRATION AND EDUCATION

BOARD OF NATURAL RESOURCES
AND CONSERVATION

HON. JOHN C. WATSON, *Chairman*

LAURENCE L. SLOSS, PH.D., *Geology*

ROGER ADAMS, PH.D., D.Sc., LL.D., *Chemistry*

ROBERT H. ANDERSON, B.S., *Engineering*

THOMAS PARK, PH.D., *Biology*

CHARLES E. OLMSTED, PH.D., *Forestry*

DEAN WILLIAM L. EVERITT, E.E., PH.D., D.ENG.,
University of Illinois

PRESIDENT DELYTE W. MORRIS, PH.D.,
Southern Illinois University

STATE GEOLOGICAL SURVEY

JOHN C. FRYE, PH.D., D.Sc., *Chief*

1557.73
Gr-219
c-3

ILLINOIS STATE GEOLOGICAL SURVEY Urbana, Illinois FULL TIME STAFF

JOHN C. FRYE, Ph.D., D.Sc., *Chief*

ENID TOWNLEY, M.S., *Geologist
and Assistant to the Chief*

HELEN E. McMORRIS,
Secretary to the Chief

VELDA A. MILLARD, *Junior
Assistant to the Chief*

GEOLOGICAL GROUP

M. L. THOMPSON, Ph.D., *Principal Geologist*

COAL

JACK A. SIMON, M.S., *Geologist and Head*
JOHN A. HARRISON, M.S., *Geologist*
WILLIAM H. SMITH, M.S., *Geologist*
KENNETH E. CLEGG, M.S., *Associate Geologist*
HAROLD J. GLUSKOTER, Ph.D., *Assoc. Geologist*
M. E. HOPKINS, Ph.D., *Associate Geologist*
RUSSEL A. PEPPERS, Ph.D., *Associate Geologist*
FREDERICK N. MURRAY, Ph.D., *Asst. Geologist*

GROUND-WATER GEOLOGY AND GEOPHYSICAL EXPLORATION

ROBERT E. BERGSTROM, Ph.D., *Geologist and
Head*
MERLYN B. BUHLE, M.S., *Geologist*
JAMES E. HACKETT, Ph.D., *Geologist*
JOHN P. KEMPTON, Ph.D., *Associate Geologist*
LYLE D. MCGINNIS, Ph.D., *Assoc. Geophysicist*
JOHN E. BRUECKMANN, M.A., *Assistant Geologist*
KEROS CARTWRIGHT, M.S., *Assistant Geologist*
PAUL C. HEIGOLD, M.S., *Assistant Geophysicist*
GEORGE M. HUGHES, Ph.D., *Assistant Geologist*
RONALD A. LANDON, M.S., *Assistant Geologist*
KEMAL PISKIN, M.S., *Assistant Geologist*
MANOUTCHEHR HEIDARI, B.S., *Research Assistant*
JEAN I. LARSEN, M.A., *Research Assistant*
MARGARET J. CASTLE, *Asst. Geol. Draftsman*
(on leave)
VERENA M. COLVIN, *Technical Assistant*
CHARLES R. LUND, *Technical Assistant*
SHIRLEY A. MASTERS, B.S., *Technical Assistant*

CLAY RESOURCES AND CLAY MINERAL TECHNOLOGY

W. ARTHUR WHITE, Ph.D., *Geologist and Head*
BRUCE F. BOHOR, Ph.D., *Associate Geologist*
SHIRLEY M. BREMSER, B.S., *Research Assistant*

CHEMICAL GROUP

GLENN C. FINGER, Ph.D., *Principal Chemist*

O. W. REES, Ph.D., *Principal Research Chemist*

RUTH C. LYNGE, *Technical Assistant*

ANALYTICAL CHEMISTRY

NEIL F. SHIMP, Ph.D., *Chemist and Head*
JUANITA WITTERS, M.S., *Physicist*
WILLIAM J. ARMON, M.S., *Associate Chemist*
CHARLES W. BEELER, M.A., *Associate Chemist*
JOHN A. SCHLEICHER, B.S., *Associate Chemist*
DAVID B. HECK, B.S., *Assistant Chemist*
JOHN K. KUHN, B.S., *Assistant Chemist*
RICHARD H. BURROUGHS, B.A., *Research Asst.*
JANE V. DRESBACK, B.S., *Research Assistant*
PAUL E. GARDNER, *Technical Assistant*
GEORGE R. JAMES, *Technical Assistant*
BENJAMIN F. MANLEY, *Technical Assistant*

FLUORINE CHEMISTRY

G. C. FINGER, Ph.D., *Acting Head*
DONALD R. DICKERSON, Ph.D., *Assoc. Chemist*

FRANCES H. ALSTERLUND, A.B., *Research Asst.*
OIL AND GAS

DONALD C. BOND, Ph.D., *Head*
T. F. LAWRY, B.S., *Assoc. Petrol. Engineer*
R. F. MAST, M.S., *Assoc. Petrol. Engineer*
WAYNE F. MEENTS, *Assoc. Geological Engineer*
HUBERT M. BRISTOL, M.S., *Assistant Geologist*
RICHARD H. HOWARD, M.S., *Assistant Geologist*
DAVID L. STEVENSON, M.S., *Assistant Geologist*
JACOB VAN DEN BERG, M.S., *Assistant Geologist*
ELTON E. HILL, B.A., *Research Assistant*

STRATIGRAPHY AND AREAL GEOLOGY

H. B. WILLMAN, Ph.D., *Geologist and Head*
ELWOOD ATHERTON, Ph.D., *Geologist*
CHARLES COLLINSON, Ph.D., *Geologist*
HERBERT D. GLASS, Ph.D., *Geologist*
DAVID H. SWANN, Ph.D., *Geologist*
T. C. BUSCHBACH, Ph.D., *Associate Geologist*
LOIS S. KENT, Ph.D., *Associate Geologist*
JERRY A. LINEBACK, Ph.D., *Assistant Geologist*
GLENDA S. CORDON, B.S., *Research Assistant*
ROBERT W. FRAME, *Supervisory Tech. Asst.*
J. STANTON BONWELL, *Technical Assistant*
JOSEPH F. HOWARD, *Assistant*

INDUSTRIAL MINERALS

J. E. LAMAR, B.S., *Geologist and Head*
JAMES C. BRADBURY, Ph.D., *Geologist*
JAMES W. BAXTER, Ph.D., *Associate Geologist*
RICHARD D. HARVEY, Ph.D., *Associate Geologist*
RALPH E. HUNTER, Ph.D., *Assistant Geologist*

ENGINEERING GEOLOGY AND TOPOGRAPHIC MAPPING

W. CALHOUN SMITH, Ph.D., *Geologist in charge*
PAUL B. DUMONTELLE, M.S., *Assistant Geologist*
PATRICIA M. MORAN, B.A., *Research Assistant*

COAL CHEMISTRY

G. ROBERT YOHE, Ph.D., *Chemist and Head*

PHYSICAL CHEMISTRY

JOSEPHUS THOMAS, JR., Ph.D., *Chemist and
Head*
GARY S. BENSON, B.A., *Research Assistant*

CHEMICAL ENGINEERING

H. W. JACKMAN, M.S.E., *Chemical Engineer and
Head*
R. J. HELFINSTINE, M.S., *Mechanical and
Administrative Engineer*
LEE D. ARNOLD, B.S., *Assistant Engineer*
WALTER E. COOPER, *Technical Assistant*
JOHN P. MCCLELLAN, *Technical Assistant*
EDWARD A. SCHAEDE, *Technical Assistant*

MINERAL ECONOMICS GROUP

HUBERT E. RISSE, PH.D., *Principal Mineral Economist*

W. L. BUSCH, A.B., *Associate Mineral Economist*

R. L. MAJOR, M.S., *Assistant Mineral Economist*

ADMINISTRATIVE GROUP

EDUCATIONAL EXTENSION

ENID TOWNLEY, M.S., *Geologist and Acting Head*
GEORGE M. WILSON, M.S., *Geologist*
DAVID L. REINERTSEN, A.M., *Associate Geologist*
WILLIAM E. COTE, A.B., *Research Assistant*
CAROL ANN GOERINGER, B.A., *Research Assistant*
HELEN S. JOHNSTON, B.S., *Technical Assistant*

PUBLICATIONS

G. ROBERT YOHE, PH.D., *Coordinator*
BETTY M. LYNCH, B.ED., *Technical Editor*
LOIS S. HAIG, *Technical Editor (on leave)*
MARIE L. MARTIN, *Geologic Draftsman*
PENNY M. BARROWS, B.A., *Asst. Geol. Draftsman*
LESLIE R. LEWIS, *Asst. Geol. Draftsman*
WILLIAM DALE FARRIS, *Research Associate*
RUBY D. FRISON, *Technical Assistant*
BEULAH M. UNFER, *Technical Assistant*

MINERAL RESOURCE RECORDS

VIVIAN GORDON, *Head*
HANNAH KISTLER, *Supervisory Tech. Asst.*
CONSTANCE ARMSTRONG, *Technical Assistant*
SUE ELLEN AUGER, B.S., *Technical Assistant*
PAULA K. GIERTZ, *Technical Assistant*
PHYLLIS M. PINDER, B.A., *Technical Assistant*
ELIZABETH SPEER, *Technical Assistant*

TECHNICAL RECORDS

BERENICE REED, *Supervisory Technical Assistant*
MIRIAM HATCH, *Technical Assistant*
HESTER L. NESMITH, B.S., *Technical Assistant*

FINANCIAL OFFICE

VELDA A. MILLARD, *in charge*
MARJORIE J. HATCH, *Clerk IV*
VIRGINIA C. SMITH, B.S., *Clerk IV*
PAULINE MITCHELL, *Clerk-Typist III*

EMERITI

M. M. LEIGHTON, PH.D., D.SC., *Chief, Emeritus*
ARTHUR BEVAN, PH.D., D.SC., *Principal Geologist, Emeritus*
J. S. MACHIN, PH.D., *Principal Chemist, Emeritus*
W. H. VOSKUIL, PH.D., *Principal Mineral Economist, Emeritus*
G. H. CADY, PH.D., *Senior Geologist, Emeritus*
A. H. BELL, PH.D., *Geologist, Emeritus*
GEORGE E. EKBLAW, PH.D., *Geologist, Emeritus*
R. J. PIERSOL, PH.D., *Physicist, Emeritus*
L. D. MCVICKER, B.S., *Chemist, Emeritus*
LESTER L. WHITING, M.S., *Geologist, Emeritus*
B. J. GREENWOOD, B.S., *Mechanical Engineer, Emeritus*
DOROTHY ROSE ELAM, B.S., *Technical Editor, Emerita*
MEREDITH M. CALKINS, *Geologic Draftsman, Emerita*

January 1, 1966

LIBRARY

LIESELOTTE F. HAAK, *Geological Librarian*
JESSICA A. MERZ, *Technical Assistant*

GENERAL SCIENTIFIC INFORMATION

PEGGY H. SCHROEDER, B.A., *Research Assistant*
RAMONA R. ROWDEN, *Technical Assistant*

SPECIAL TECHNICAL SERVICES

GLENN G. POOR, *Research Associate (on leave)*
MERLE RIDGLEY, *Research Associate*
GILBERT L. TINBERG, *Technical Assistant*
WAYNE W. NOFFTZ, *Supervisory Tech. Assistant*
DONOVON M. WATKINS, *Technical Assistant*
MARY M. SULLIVAN, *Supervisory Tech. Assistant*
EMILY S. KIRK, *Supervisory Technical Assistant*

CLERICAL SERVICES

SANDRA KAY FLEWELLING, *Clerk-Stenographer II*
HAZEL V. ORR, *Clerk-Stenographer II*
DOROTHY M. SPENCE, *Clerk-Stenographer II*
JANE L. WASHBURN, *Clerk-Stenographer II*
SHARON K. FILLENWARTH, *Clerk-Stenographer I*
CYNTHIA L. GOKEN, *Clerk-Stenographer I*
MAGDELINE E. HUTCHISON, *Clerk-Stenographer I*
EDNA M. YEARGIN, *Clerk-Stenographer I*
JOANN AUBLE, *Clerk-Typist II*
LINDA D. RENTFROW, *Clerk-Typist II*
MARY E. DECKARD, *Clerk-Typist I*
PAULINE F. TATE, *Clerk-Typist I*
JAMES C. ZINDARS, *Messenger-Clerk II*

AUTOMOTIVE SERVICE

ROBERT O. ELLIS, *Garage Superintendent*
DAVID B. COOLEY, *Automotive Mechanic*
EVERETTE EDWARDS, *Automotive Mechanic (on leave)*
JAMES E. TAYLOR, *Automotive Mechanic*

RESEARCH AFFILIATES AND CONSULTANTS

RICHARD C. ANDERSON, PH.D., *Augustana College*
DOUGLAS A. BLOCK, PH.D., *Wheaton College*
W. F. BRADLEY, PH.D., *University of Texas*
JULIAN R. GOLDSMITH, PH.D., *University of Chicago*
RALPH E. GRIM, PH.D., *University of Illinois*
S. E. HARRIS, JR., PH.D., *Southern Illinois University*
I. EDGAR ODOM, PH.D., *Northern Illinois University*
T. K. SEARIGHT, PH.D., *Illinois State University*
PAUL R. SHAFFER, PH.D., *University of Illinois*
HAROLD R. WANLESS, PH.D., *University of Illinois*
GEORGE W. WHITE, PH.D., *University of Illinois*

Topographic mapping in cooperation with the United States Geological Survey.

CONTENTS

	PAGE
Introduction	7
Location	7
General geology	7
Previous investigations	10
Geophysical data analysis	11
Gravity measurements	11
Seismic measurements	12
Acknowledgments	13
Regional gravity field and structure	13
Isostatic control of basin formation	14
Precambrian basement surface	16
Basement wells and aeromagnetic control	16
Gravity interpretation	16
Seismic interpretation	19
Basement configuration	20
DesPlaines Disturbance	25
Precambrian gravity field	25
Summary and conclusions	27
References	28

ILLUSTRATIONS

FIGURE	PAGE
1. Regional structure of top of the Galena Dolomite	9
2. Generalized stratigraphic column of northeastern Illinois	10
3. Profiles of Bouguer and free-air anomalies and surface elevation along a north-south line between R. 3 E. and R. 4 E.	12
4. Regional relation between Bouguer gravity values and the elevation of Galena Dolomite for areas in the Midwest	13
5. Average basement elevations versus average Bouguer gravity anomaly values for each square degree in Illinois with least-square line	14
6. Generalized cross section of the crust and upper mantle, and the asso- ciated free-air anomaly along a north-south line through eastern Illinois	15
7. Average densities of 10-foot thickness intervals and of stratigraphic units in Bethlehem Steel No. 1 Fee, sec. 28, T. 37 N., R. 6 W., Porter County, Indiana, derived from the gamma-gamma log	17
8. Average densities of 10-foot thickness intervals and of stratigraphic units in Reed No. 1 McCoy, sec. 20, T. 35 N., R. 9 E., Will County, Illinois, derived from the gamma-gamma log	18

FIGURE	PAGE
9. Average transit time of 10-foot thickness intervals and of stratigraphic units in Bethlehem Steel No. 1 Fee, sec. 28, T. 37 N., R. 6 W., Porter County, Indiana, derived from the sonic log	18
10. Corrected reflection times on the seismic traverse in northeastern Illinois	19
11. Seismic reflection record at station 41, sec. 19, T. 39 N., R. 9 E.	20
12. Seismic reflection record at station 63, sec. 20, T. 41 N., R. 6 E., exhibiting three multiple reflections	21
13. Precambrian crystalline basement structure in northeastern Illinois based on bore holes and geophysical data	22
14. Precambrian crystalline basement structure in northeastern Illinois based on extrapolation from shallow structures by Buschbach (1964, fig. 6)	23
15. A profile along line A-A' (fig. 13) showing the structure of the top of the basement and of the overlying sediments in relation to the gravity and magnetic fields	24
16. Profile of basement structure across the graben area at the culmination of Ironton deposition	24
17. Reconstruction of the gravity field over the graben in northeastern Illinois	26

PLATE

1. Geophysical equipment used in exploration in northeastern Illinois	8
2. Simple Bouguer and residual gravity of northeastern Illinois(<i>in pocket</i>)	

TABLES

TABLE	PAGE
1. Wells to basement in northeastern Illinois and adjacent areas	16

CRUSTAL TECTONICS AND PRECAMBRIAN BASEMENT IN NORTHEASTERN ILLINOIS

Lyle D. McGinnis

ABSTRACT

Seismic reflection, gravity, and aeromagnetic surveys were used in northeastern Illinois to determine the depth to the Precambrian crystalline rocks. An inverse relation between basement structures and Bouguer gravity anomalies was found. The gravity anomalies are caused by variations in crustal densities. Low-density areas, on a regional scale, have developed into arches, whereas areas of high density have developed into basins. These broad undulations in the crust produce tensional stresses that allow fractures to develop along the crustal heterogeneities. Fracturing permits rather local movements to occur in response to isostatic adjustments of high- and low-density crustal blocks.

A basement fault zone, north of and parallel to the Sandwich Fault Zone, is suggested by the geophysical data.

INTRODUCTION

When the Illinois State Geological Survey in 1962 began a study of water resources and their management, under the auspices of the Northeastern Illinois Metropolitan Area Planning Commission (NIMAPC), to help plan future water supplies in the Chicago metropolitan area, geophysical exploration programs were included to broaden the scope of the study and to decrease the cost of obtaining the required information. In place of expensive deep drilling, gravity and reflection seismic surveys were made in 1962 and 1963 to help define the deep aquifers. This report is an interpretation of crustal tectonics and the Precambrian surface, based on the geophysical and geologic data acquired. The geophysical instruments used are shown on plate 1.

Location

Northeastern Illinois, as defined here, comprises that area north of T. 30 N. and east of R. 2 E., or roughly, the part of Illinois north of latitude 41° N. and east of longitude 89° W. It includes southeastern Winnebago, eastern LaSalle, northern Livingston, eastern Ogle, and all of Kendall, Boone, McHenry, Lake, DeKalb, Kane, DuPage, Cook, Grundy, Will, and Kankakee Counties. The area is shaded on the index map in figure 1.

General Geology

A generalized columnar section (fig. 2) shows the stratigraphy of northeastern Illinois. The region is centered over the Kankakee Arch, a broad, positive, structural feature separating the Illinois Basin to the south from the Michigan Basin to the northeast and connecting the Wisconsin and Cincinnati Arches.



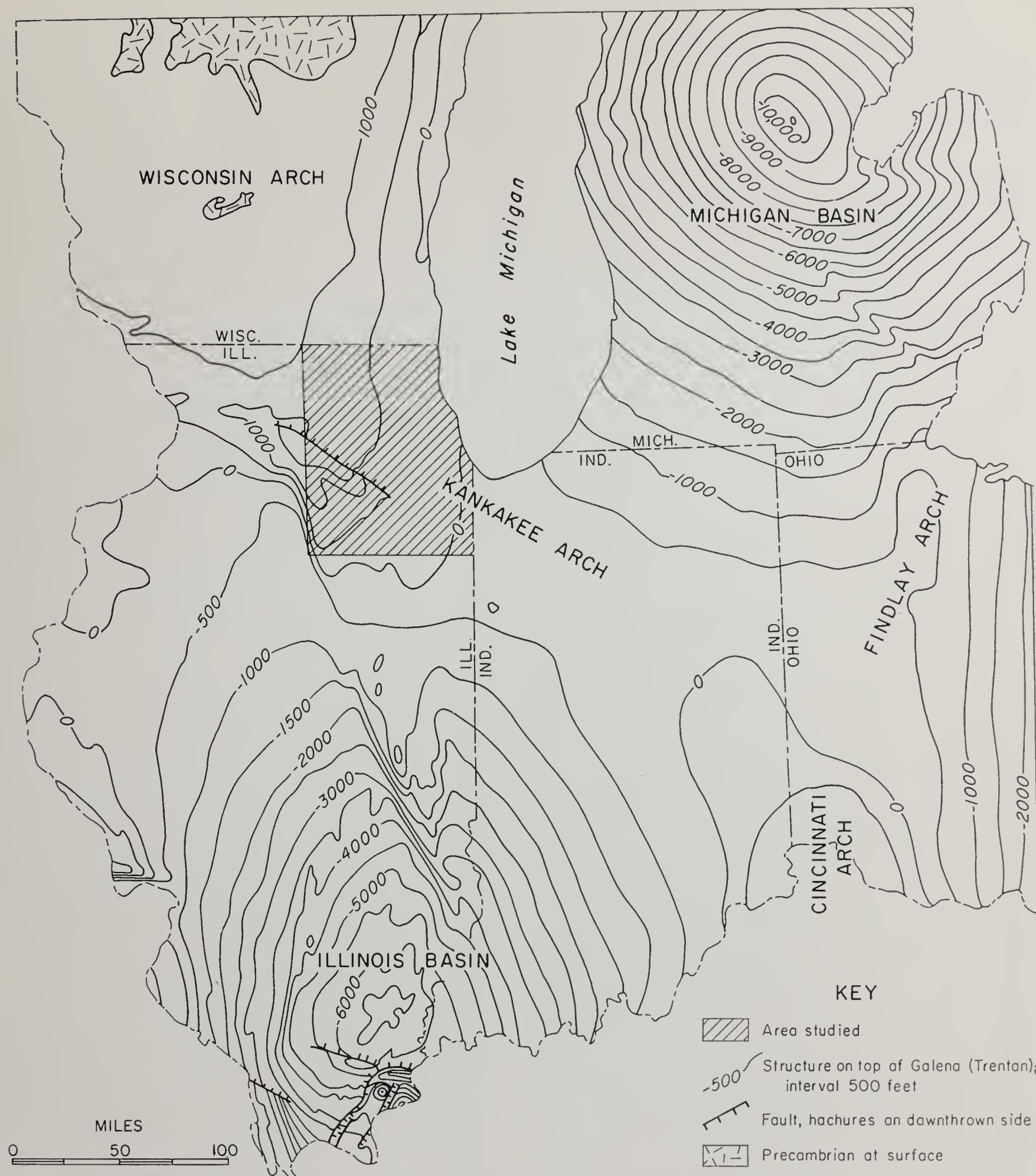


FIG. 1—Regional structure of the top of the Galena Dolomite. Area studied is shaded.

Figure 1 shows the regional structure as it was contoured on the top of the Galena Dolomite. The Sandwich Fault Zone, on the southern flank of the Kankakee Arch, is a high-angle fault downthrown to the north as much as 1000 feet in places. At the southeastern end, in Will County, the northern side of the fault zone is upthrown more than 125 feet. In Cook County, the DesPlaines

Disturbance covers an area about 25 miles square in which the rocks are extensively faulted. Within the disturbed zone the rocks have, in general, been uplifted, but down-faulted blocks have preserved Pennsylvanian (?) and Mississippian rocks that are missing in adjoining areas (Emrich and Bergstrom, 1962). Dolomite of Silurian age is the uppermost bedrock surrounding the disturbance.

PL. 1—Geophysical equipment used in exploration in northeastern Illinois. (A) Hammer seismograph used in shallow exploration. (B) Gravity meter used to determine variations in rock densities. (C) Reflection-refraction seismograph used in the study of the deep structure.

SYSTEM	SERIES	GROUP or FORMATION	LOG
QUATER-NARY	Pleisto-cene		
PENNSYL-VANIAN		Carbondale Spoon	
SILURIAN	Niagara-ran	Racine Waukesha Joliet	
	Alexan-drian	Kankakee Edgewood	
ORDOVICIAN	Cincin-natian	Maquoketa	
	Champ-lainian	Galena-Platteville	
		Glenwood	
		St. Peter	
	Cana-dian	Prairie du Chien	
		Eminence Potosi	
CAMBRIAN	Knox Megagroup	Franconia	
		Iron-ton	
		Galesville	
		Eau Claire	
		Mt. Simon	

The bedrock surface is underlain by Silurian rocks in the eastern part of the area, the Cincinnati (Upper Ordovician) Maquoketa Group in the center, and the Champlainian (Middle Ordovician) Galena, Platteville, and Ancell Groups in the western part. In the southwestern part of the area, Pennsylvanian sediments onlapping the older Paleozoic rocks form the surface. The oldest rocks at the bedrock surface are late Cambrian in age and are locally present along the Sandwich Fault Zone in the western part of the region. The areal geology of the bedrock surface has been reported by Suter et al. (1959), Kempton (1962), and Willman and Payne (1942). Glacial deposits, over 500 feet thick in some areas, cover the bedrock.

Previous Investigations

Pemberton (1954) conducted a gravity survey of the DesPlaines area to clarify the structural relations of the disturbance. Maps of regional anomalies of the vertical magnetic intensity in Illinois were prepared by McGinnis and Heigold in 1961, and a gravity survey of the western quarter of the area included in the present study was reported by McGinnis, Kempton, and Heigold in 1963. Beck (1965) gave an interpretation of the basement surface in northeastern Illinois based on an aeromagnetic survey flown in 1960 by the U. S. Geological Survey.

Geophysical investigations in northeastern Illinois have been aided considerably by numerous geologic studies of the area, which were instigated by the needs of the growing metropolitan community. Major geologic structures in northeastern Illinois were defined by Cady (1920), Thwaites (1927), Ekblaw (1938), and Willman and Payne (1942). Cady examined the LaSalle Anticline, describing its structure, age, causes of deformation, and its relation to the Illinois Basin. Thwaites discussed the structural elements of northern Illinois and their interrelations. Ekblaw suggested that the Illinois portion of the Kankakee Arch connects the Wisconsin and Cincinnati Arches. Willman and Payne studied the structure in an area

FIG. 2—Generalized stratigraphic column of northeastern Illinois. The Mt. Simon Sandstone rests unconformably on Precambrian crystalline rocks.

centering around LaSalle County and mapped the Sandwich Fault Zone and numerous other structures.

Willman and Templeton (1951) examined the stratigraphy and structural geology of northern Illinois. Suter et al. (1959) described the sedimentary column, compiled a map of the bedrock topography, and mapped the structure and thickness of the main rock units. The stratigraphy and structure of the Cambrian and Ordovician formations were described by Buschbach in 1964.

Geophysical Data Analysis

Gravity Measurements

Observed gravity measurements are used in the interpretation of geology by comparing them with theoretical values of gravity. The difference between the observed gravity and the calculated theoretical gravity value at an observation site is called a gravity anomaly. If the theoretical value includes the effects of the shape and rotation of the earth, the elevation of the observation site, and the local relief or terrain, the anomaly is termed a Bouguer gravity anomaly. Gravity measurements were made in the western part of the area with a Worden meter and in the eastern section with a World-Wide instrument. Both are null-reading, temperature-compensated instruments.

Terrain corrections were not applied in this study because the topographic relief throughout the surveyed area is low. Meter drift was determined by repeated readings at a base station during the field day. Free-air and Bouguer corrections, where:

$$\begin{aligned} \text{Free-air gravity anomaly} = & \\ & \text{observed gravity} \\ & + \text{elevation correction (sea level)} \\ & - \text{theoretical gravity} \end{aligned} \quad (1)$$

and

$$\begin{aligned} \text{Bouguer gravity anomaly} = & \\ & \text{observed gravity} \\ & + \text{elevation (free air) correction} \\ & + \text{mass (Bouguer) correction} \\ & + \text{terrain correction} \\ & - \text{theoretical gravity,} \end{aligned} \quad (2)$$

were combined. The density for glacial drift in the area was assumed to be 2.35 gm/cc,

as McGinnis, Kempton, and Heigold determined it in 1963. The gravity survey of north-eastern Illinois was tied to the gravity control network in North America, at the Janesville-Beloit, Wisconsin, Station (WA-175), described by Behrendt and Woollard (1961). Gravity measurements were made at section corners and bench marks. Elevations listed at these points on U. S. Geological Survey topographic maps may have an error of ± 1 foot, which is permissible for regional gravity surveys. Meter drift and the combined free-air and Bouguer corrections contributed errors of ± 0.05 milligals and ± 0.06 milligals, respectively, to the Bouguer gravity value (Heigold, McGinnis, and Howard, 1964).

Theoretical gravity is based on the 1930 International Gravity Formula:

$$g_{\phi} = [978.049 (1 + 0.0052884 \sin^2 \phi - 0.0000059 \sin^2 2\phi)] \quad (3)$$

where g_{ϕ} is the sea level gravity at latitude ϕ . Stations were located accurately to ± 0.1 minute of latitude, so that theoretical gravity was subject to an error of ± 0.08 milligals. It follows that the Bouguer anomaly is accurate to at least ± 0.19 milligals. Plate 2 is the Bouguer gravity anomaly map of north-eastern Illinois.

In interpreting a gravity map, it is helpful to separate regional from local trends. When regional trends are removed from Bouguer gravity data, the result is called a residual Bouguer anomaly. The residual anomalies are the red lines on plate 2. For this study, the regional gravity effects were removed by the least-square method outlined by Mack (1963) and by Coons, Mack, and Strange (1964), which was reviewed by Heigold, McGinnis, and Howard (1964).

The area surveyed was of uneven shape but had about 5500 evenly distributed gravity stations. As Mack (1963) recommended that nearly square areas be used in the residual program, the area was broken up into seven smaller overlapping areas for the derivation of residuals. Data reduction was carried out on a Control Data Corporation 1604 computer belonging to the University of Illinois.

An 11th degree power series approximation to the Bouguer anomaly surface was fitted to the regional trend surface. When this surface is subtracted from the Bouguer an-

omaly surface to produce a residual map, most of the effects of extremely deep-seated density contrasts in the crust and upper mantle are eliminated. The residual map (pl. 2) is therefore controlled primarily by upper crustal and sedimentary density contrasts.

Free-air gravity anomalies do not include the gravitational effect of mass between the level of observation and sea level; otherwise they are similar to Bouguer anomalies. Free-air anomalies can be used to measure degree of isostatic compensation. In Illinois, because of the low relief, Bouguer and free-air anomalies are much alike (fig. 3). Bouguer anomalies can therefore be used as a first approximation to free-air anomalies, eliminating the need for constructing another map for the free-air gravity field. When free-air anomalies are averaged for wide areas, they generally tend to average zero, which proves isostasy does exist, since the mass above sea level must be compensated by a mass deficiency somewhere in the crust or upper mantle. Whether or not compensation takes place depends to a great extent on the lateral dimensions and mass of an anomalous body. Woollard (1962) stated that for geologic features more than 250 km (~ 155 miles) wide compensation is likely. If free-air anomalies do not average zero over areas having dimensions of that order, it can be assumed that the crust is not in isostatic equilibrium. Fea-

tures of smaller dimension will, in general, be supported by the crust, and their masses then become part of the average regional crustal mass, which may be compensated regionally. Exceptions to the above limits are, of course, found, as will be discussed later.

Seismic Measurements

Seismic reflection measurements were made with a Seismograph Service Corporation 24-channel reflection-refraction seismograph (pl. 1C) modified into a smaller 12-channel instrument for Illinois Geological Survey use. Multiple geophones per trace were found to be necessary for optimum results. Reflection times (from the shot, to basement, to geophone) were corrected to a sea level datum. Velocities were obtained in the bedrock from sonic logs, and refraction shooting provided mean glacial drift velocities in the area. In areas where the drift exceeded 100 feet thick, the reflection-refraction seismograph was used, but where the drift was less than 100 feet thick, a hammer seismograph (Geophysical Specialties Company) was used (pl. 1A).

Drift thickness was calculated from quadrangle topographic maps and a bedrock topography map (McGinnis, 1965). The equa-

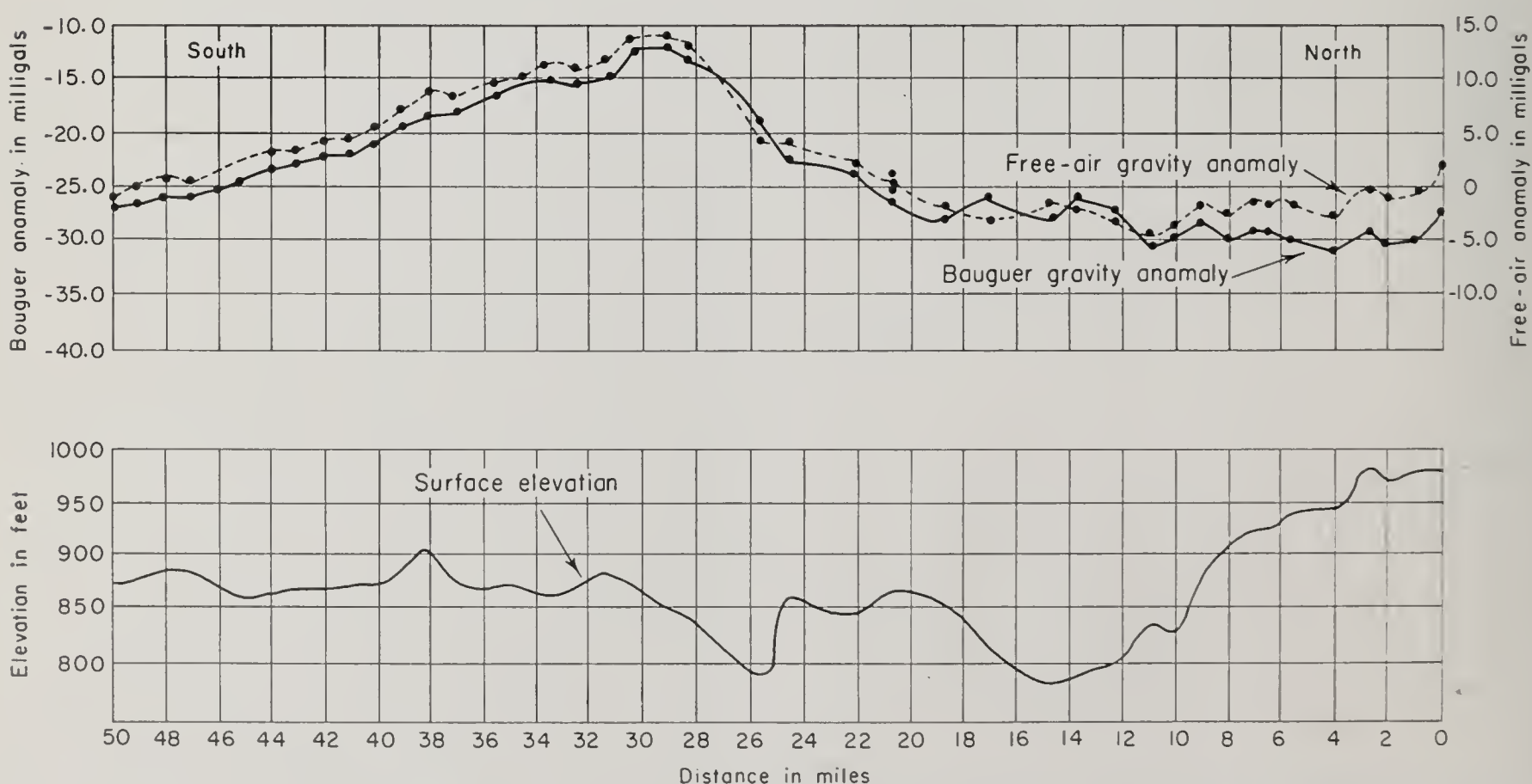


FIG. 3—Profiles of Bouguer and free-air anomalies and surface elevation along a north-south line between R. 3 E. and R. 4 E.

tion used to correct the basement reflection time to sea level is:

$$\text{Reflection time} = (\text{total time} - \text{drift time} - \text{bedrock to sea level time} + \text{shot depth time}). \quad (4)$$

All times are two-way times except for the shot depth time, which is uphole time.

Acknowledgments

This study was supported by the Illinois State Geological Survey and is adapted from portions of a doctoral dissertation submitted to the Graduate College of the University of Illinois in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Geology. Additional support was provided by NIMAPC as part of a water resources development and management study. Seismograph Service Corporation, Tulsa, Oklahoma, through the mediation of R. S. Finn, donated a reflection-refraction seismograph, which was modified by F. A. Roberts, formerly with the University of Illinois Physics Research Laboratory. Geophysical field crews were provided by the Illinois Survey and NIMAPC.

P. C. Heigold made most of the gravity observations. G. P. Woollard and Joseph Laurence of the University of Wisconsin contributed unpublished regional gravity data for Illinois that I have used in figure 5. M. E. Beck of the U.S. Geological Survey made available aeromagnetic data and interpretations of the magnetic field of northeastern Illinois.

REGIONAL GRAVITY FIELD AND STRUCTURE

The Bouguer gravity anomaly map of the United States (Woollard and Joesting, 1964) shows the central United States as a region of generally low gravity gradients compared with the rest of the country. High gradients are found only in the general vicinity of the midcontinent gravity high (Thiel, 1956) that extends from the western tip of Lake Superior into southern Kansas. Immediately east of the high the regional gravity field is quite flat, with a series of broad, low-amplitude, Bouguer anomaly lows surrounding regions of somewhat higher Bouguer anomaly values

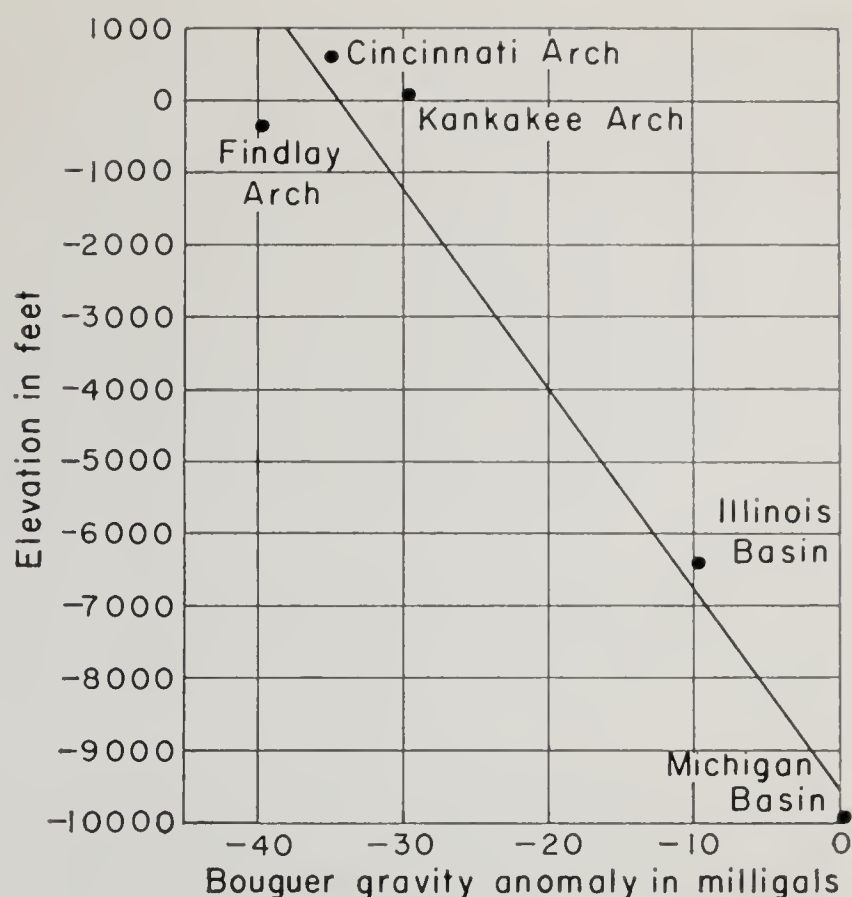


FIG. 4—Regional relation between Bouguer gravity values and the elevation of Galena Dolomite for areas in the Midwest. Bouguer values are estimated from a map published by Woollard and Joesting (1964). Elevations are estimated from a tectonic map of the United States by Cohee et al. (1961).

that are centered in southeastern Missouri and central Michigan. The average Bouguer anomaly value of the area surveyed in detail for the present study is low compared with those of southeastern Missouri and central Michigan, but it is higher than that of central Wisconsin.

Comparison of regional geologic structures and Bouguer gravity anomalies in the central United States permits a closer examination of local structure in northeastern Illinois. An inverse relation is apparent between broad regional structure and Bouguer anomalies. Figure 4 shows the general relation between regional Bouguer gravity anomaly values, determined from the Bouguer map of the United States, and regional structure, taken from the Cohee et al. (1961) tectonic map of the United States. Structural highs are approximately coincident with Bouguer anomaly lows. Basin deeps have anomalies more positive than the surrounding arches and domes.

Woollard (1962) pointed out the inverse relation of regional gravity to structure in the Illinois Basin. Henderson and Zietz (1958) showed the same inverse relation along the Cincinnati and Kankakee Arches in Indiana. Hinze (1963) noted the same relation in the Michigan Basin and suggested

isostasy as the causative factor. In 1959 Lyons examined the midcontinent gravity high and noted the series of Paleozoic basins throughout its extent. Lyons concluded that gravity highs could not be explained by sedimentary lithology or structure, and therefore the basins were produced by continuing subsidence of thick, high-density basic rocks of Precambrian age. Structures involving Paleozoic and younger rocks thus can be related to density distribution within the Precambrian crystalline rocks.

In a summary of the gravity field in the central United States, Woollard (1962) concluded

. . . the key to an understanding of gravity relations in the midcontinent area appears to be a knowledge of the composition of the crystalline basement. The geologic parameters which can be most effectively related to this are: a) knowledge of the Precambrian structural trends, b) sampling of the basement to determine its composition, and c) consideration of the type and extent of post-Cambrian igneous activity in the area.

In 1963 McGinnis, Kempton, and Heigold examined the Bouguer gravity field in the western part of the area discussed here and noted an inverse relation between gravity and structure. They found that the mass eroded from the upthrown side of the Sandwich Fault would be equivalent to the mass required to remove the negative gravity anomalies. The significance of this will be explained in the final section of this report.

Figure 5 shows a least-square line through a plot of average basement elevations in Illinois (from Bell et al., 1964) versus average Bouguer anomaly values from an unpublished map by Joseph Laurence (now incorporated in the Bouguer gravity anomaly map of the United States, published in 1964 by Woollard and Joesting). Bouguer values were averaged over each square degree of latitude and longitude, as were basement elevations. The correlation coefficient between elevations and gravity values is $-.82$, which indicates a strong inverse relation between gravity anomalies and basement structure. When the free-air gravity field is estimated from Bouguer anomaly values over the Illinois Basin, the gravity field is found to increase to the

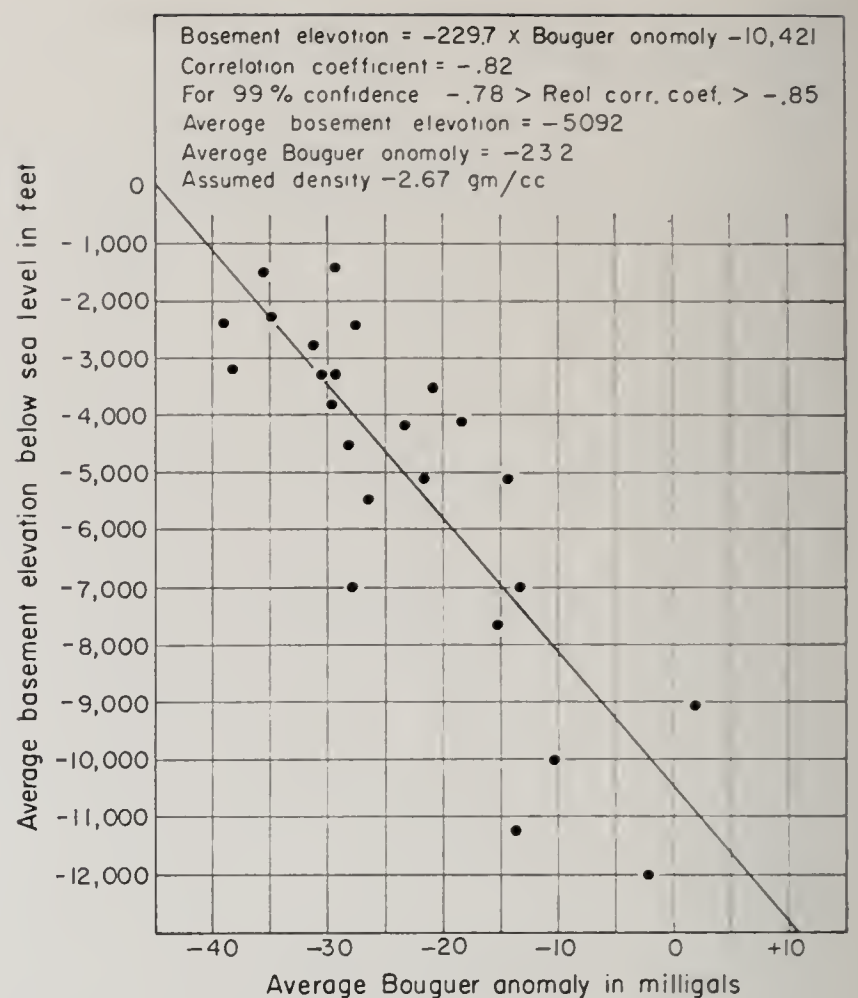


FIG. 5—Average basement elevations versus average Bouguer gravity anomaly values for each square degree in Illinois with least-square line.

south by an amount four times that which would be caused by the lowering in elevation. If the geologic correction were applied to account for more than 10,000 additional feet of sediment in the basin than is present in northern Illinois, the increase in theoretical Bouguer values to the south, due to the elevation decrease, would be more than eliminated. Average free-air values in the basin would also be 30 or more milligals higher than values on the surrounding arches. Figure 6 shows a generalized north-south cross section of the crust and upper mantle across Illinois and the associated, approximate, mean free-air anomaly. According to illustrations in Steinhart and Meyer (1961), crustal thickness in Illinois is rather uniform, generally about 35 km (~ 22 miles).

Isostatic Control of Basin Formation

When the Illinois and Michigan Basins and their surrounding arches and domes were examined, the arches proved to be regional Bouguer gravity negatives and the basins gravity positives. If, during crystallization of the crust, excess crustal masses in the basins and insufficient masses in the arches existed or were produced by some form of differentiation, a simple basin could have developed from gravitational forces alone. A basin

formed in this manner would contain relatively few evidences of intensive thrusting or folding, and faults would be primarily vertical. Original uplift or subsidence would be aided by subsequent erosion from the structurally positive (negative gravity anomaly or low-density) arches and deposition in the structurally negative (high-density) basins. This transfer of sediment from the arches to the basins would cause the subsiding process to continue intermittently once movement had started, but at a slower and slower over-all rate because high-density rocks would be replaced by lower density sediment.

The distribution of masses shown by gravity anomalies within the basin (Heigold, McGinnis, and Howard, 1964) might at first cause very local regions to rise or subside. As adjustments continue, a basin or an arch would grow outward, encompassing more and more area and combining smaller mass differences into one large unit. In this way it would be possible for the center of a basin or an arch to move laterally, since, with the inclusion of more separate mass units as the basin grew, the geographic center of mass of the growing basin would continuously shift.

Study of the Bouguer gravity anomalies in Illinois reveals that the density does not increase smoothly from arches to basin but varies in a patchwork pattern of local high- and low-density areas. There is, however, an average increase in density toward the basin center. I assumed for this study that

the Bouguer anomaly pattern is essentially the same now as it was in Precambrian time. If it can also be assumed that the crystalline rocks in the earth's crust below the basement surface are generally Precambrian in age with no Paleozoic recrystallization, the gravity anomalies and density differences noted above would have existed before sediment accumulation, and the gravity field would have been in Precambrian time essentially what it is today.

An argument for the gravitational development of basins and arches can be made by comparing vertical crustal movements involved in glacial isostasy in North America and Fennoscandia to movements of Paleozoic age in the stable interior of the continent. An ice mass, equivalent in thickness to the ice caps of Greenland and Antarctica, would have a gravitational attraction of about 120 to 140 milligals at its center. Such a load would, in time, depress the crust at the center of the ice mass about 3000 feet. Removal of the ice cap would result in isostatic rebound approaching preglacial elevations. Gravity anomalies that indicate mass differences sufficient to provide at least one-fourth the gravitational attraction of an ice cap can be observed in the Midwest. These differences would result in isostatic depression similar to the depression caused by ice loading. Unlike the ice mass, however, the crustal mass distribution is more or less permanent, and basin depression will therefore persist in

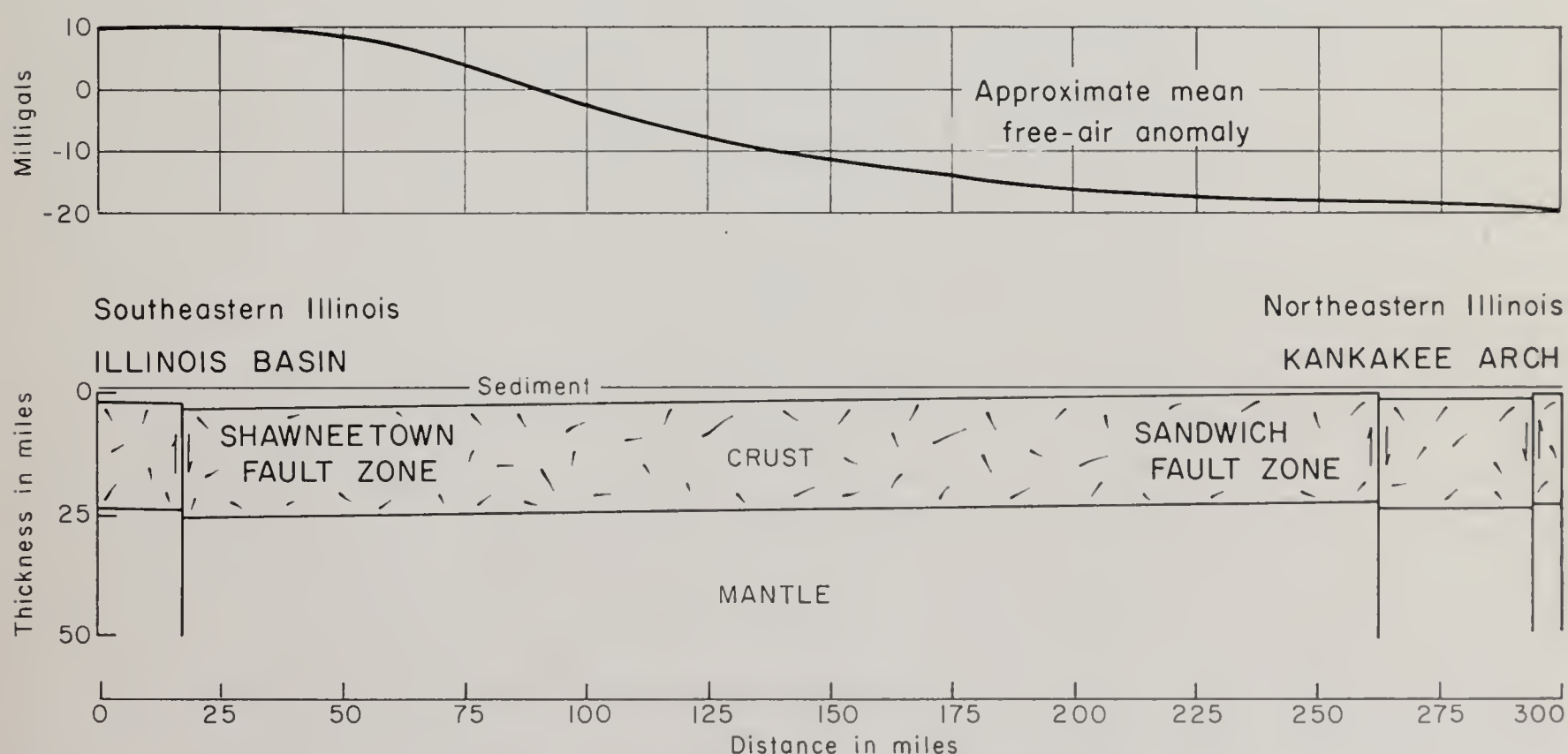


FIG. 6—Generalized cross section of the crust and upper mantle, and the associated free-air anomaly along a north-south line through eastern Illinois.

time. Accumulation of sediment in the depressions would add mass to an already overloaded crust and result in further subsidence. The limits of crustal subsidence are probably controlled not only by the original amount of excess mass but also by the density of the in-filling sediment and the strength of the crust. In time the merging of basins with arches would contribute to the cessation of further adjustments.

The concept of isostatic control of intracratonic basins is further strengthened by theoretical and experimental studies that have been made on elastic and viscous plates affected by gravity. Ramberg and Stephansson (1964) produced rather strong evidence that the development of geosynclines is brought about initially by gravitational settling and not by compressional forces.

From the above arguments it is concluded that, although no geosynclines are involved, observational data in the Midwest tend to verify the conclusions of Ramberg and Stephansson. Thus, intracratonic basins and geosynclines are genetically similar in that both are a gravitational response to a high-density crust. In fact, study of the gravity field in northeastern Illinois suggests that even small structures may be a result of broad gravitational adjustments.

PRECAMBRIAN BASEMENT
SURFACE

Basement Wells and
Aeromagnetic Control

Deep wells, seven of which reach basement in the area studied and three nearby (table 1), are the primary control points used in the present interpretation of the basement configuration. Twelve basement elevations in the study area that were based on depths calculated in an aeromagnetic study by Beck (1965) also were used. Elevations calculated from the aeromagnetic interpretations and basement elevations determined from wells are similar. A basement well (sec. 20, T. 35 N., R. 9 E.), drilled after construction of the basement map by Beck, encountered the crystalline rocks at the predicted elevation. Until a few more wells are drilled to basement, evaluation of Beck's interpretation must be delayed; however, it is heartening that the first well drilled after construction of his map fits the interpretation so closely.

Gravity Interpretation

Residual and Bouguer gravity anomalies can also be used for interpreting basement structure, but, where geologic control is scanty, it is unwise to rely solely on gravity anomalies because of their ambiguous nature. Magnetic

TABLE 1—WELLS TO BASEMENT IN NORTHEASTERN ILLINOIS AND ADJACENT AREAS

Well		County	Sec. - T. - R.	Total depth (ft)	Elevation of Precambrian (ft)	Precambrian rock type
Company, No., farm						
Seele No. 1 Fee		Winnebago	24-44N-2E	3385	—1786	Pink granite and granodiorite
Northern Illinois Oil and Gas Co. No. 1 Taylor		Boone	28-43N-3E	2998	—2104	Granodiorite
Schulte No. 1 Wyman		DeKalb	35-41N-5E	4484	—2953	Red granite
Amboy Oil and Gas Co. No. 1 McElroy		Lee	30-20N-10E	3772	—3046	Red granite
Carr No. 1 Vedovell		Lee	35-20N-10E	3653	—2653	Red granite and felsite
Lawinger No. 1 Miller		LaSalle	1-36N-4E	3659	—2788	Granite and granodiorite
Otto No. 1 Swenson		LaSalle	1-36N-5E	3725	—3037	Red granite
Vickery No. 1 Mathesius		LaSalle	32-35N-1E	3556	—2838	Red granite
Reed No. 1 McCoy		Will	20-35N-9E	4315	—3591	Red granite
Bethlehem Steel No. 1 Fee		Porter Co., Indiana	28-37N-6W	4304	—3640	Granite

fields are much more useful in the analysis of the topography of the basement surface because of the relatively minor magnetic field produced by the overlying sediments. That part of the gravity field resulting from basement relief is obscured by unconformities having considerable relief and large density contrasts. Even so, a Bouguer anomaly map can often be used to interpret regional structural trends on the basement surface.

The Bouguer gravity contours in northeastern Illinois are generally aligned in a northwest-southeast direction (pl. 2). A band of gravity highs averaging about -10 milligals lies between broad gravity lows and extends southeastward through the center of Kane County. Near T. 37 N., R. 9 E., the line of gravity highs bifurcates, with branches extending eastward and southward. Bouguer gravity anomaly values range from -48.5 milligals in the southwest to $+3.0$ milligals in the southeast. To compare Bouguer anomaly values of this report with values determined by other workers in adjacent areas, corrections must be made to compensate for differences in density assumed by different workers.

In order to examine the data from an isostatic point of view, the mean free-air anomaly must be determined. Average elevations in northeastern Illinois are about 800 feet; therefore, the -24 milligal Bouguer anomaly contour line would be roughly equivalent to the zero free-air anomaly contour line. These criteria suggest that the entire region is very nearly in equilibrium.

Lithologies providing the major density contrasts were identified from the density (gamma-gamma) logs of the Bethlehem Steel No. 1 Fee well in Porter County, northwestern Indiana, sec. 28, T. 37 N., R. 6 W. (fig. 7) and the Reed No. 1 McCoy well in Will County, Illinois, sec. 20, T. 35 N., R. 9 E. (fig. 8, table 1). Densities were interpreted from the logs by curves presented by Alger et al. (1963). It was necessary to apply a correction to the densities to compensate for the thickness of the low-density mud cake on the bore hole walls. Mud cake is thin or absent on the high-density dolomites or low-permeability shales, whereas an average mud cake thickness of a quarter of an inch was observed for most sandstones.

Comparison of the two corrected density logs (figs. 7 and 8) indicates a systematically

lower apparent density for comparable lithologies in the Reed No. 1 McCoy well, probably due to miscalibration. The apparent mean density of the Galena-Platteville is especially low. A number of the apparent den-

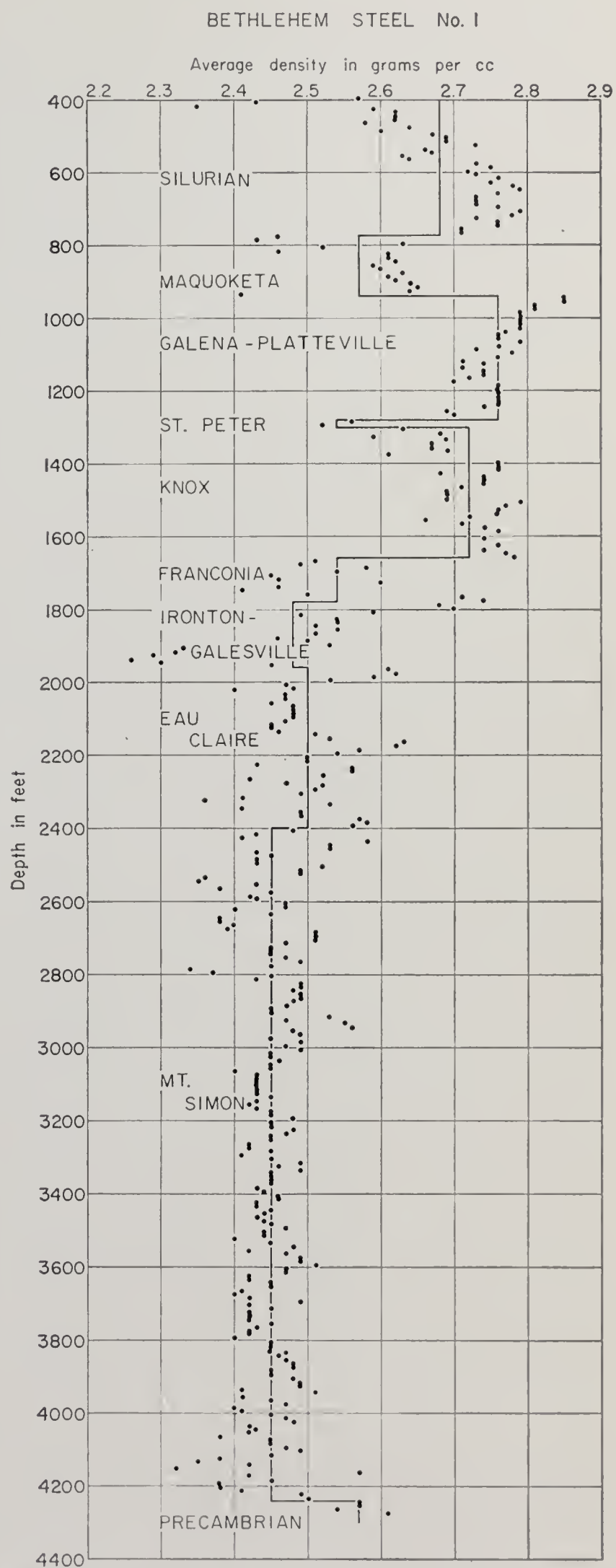


FIG. 7—Average densities of 10-foot thickness intervals and of stratigraphic units in Bethlehem Steel No. 1 Fee, sec. 28, T. 37 N., R. 6 W., Porter County, Indiana, derived from the gamma-gamma log.

sities of the Reed No. 1 McCoy well are less than 2.10 gm/cc and do not appear on the log. The logs indicate that when a low-density lithologic type is thin, its relative density is higher than normal, and when a high-density lithologic type is thin, its relative

density is lower than normal. In addition to the density contrast between drift and bed-rock, significant contrasts occur within the bedrock at the contacts of high-density Silurian and low-density Maquoketa; high-density Galena-Platteville and low-density Glen-

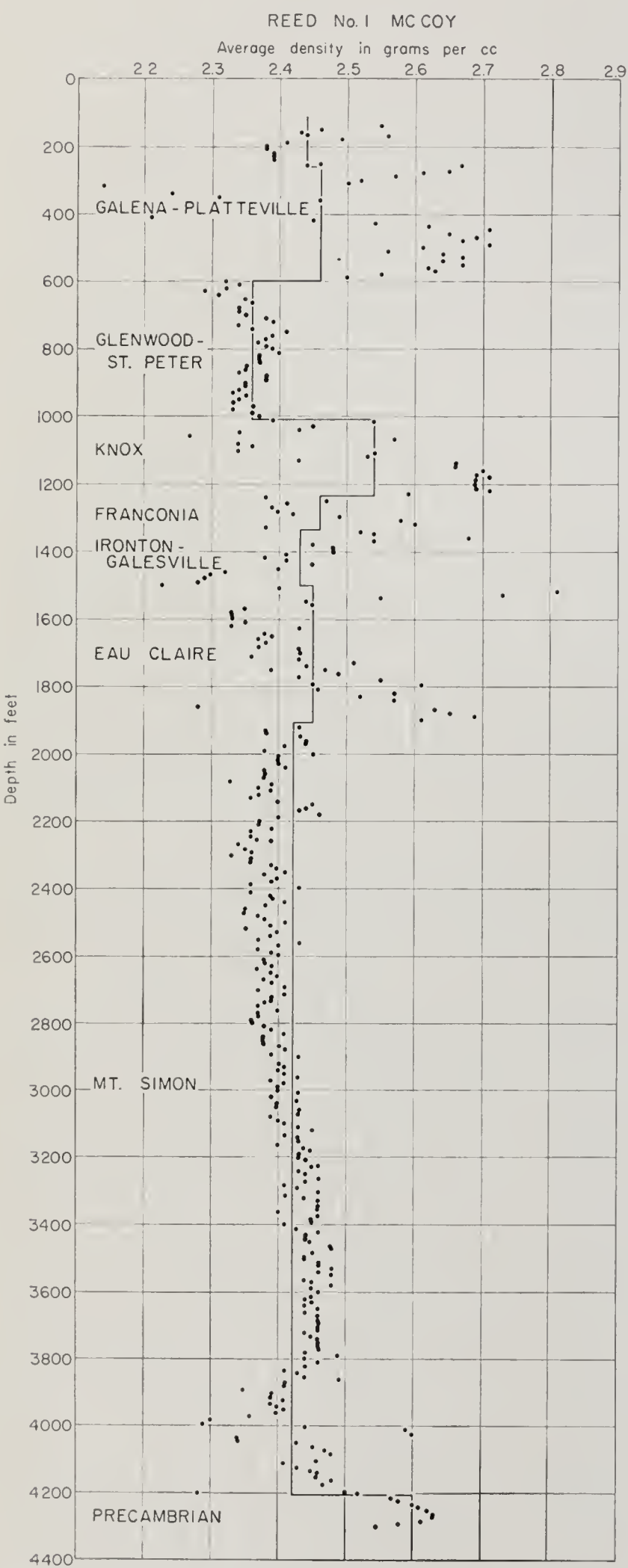


FIG. 8—Average densities of 10-foot thickness intervals and of stratigraphic units in Reed No. 1 McCoy, sec. 20, T. 35 N., R. 9 E., Will County, Illinois, derived from the gamma-gamma log.

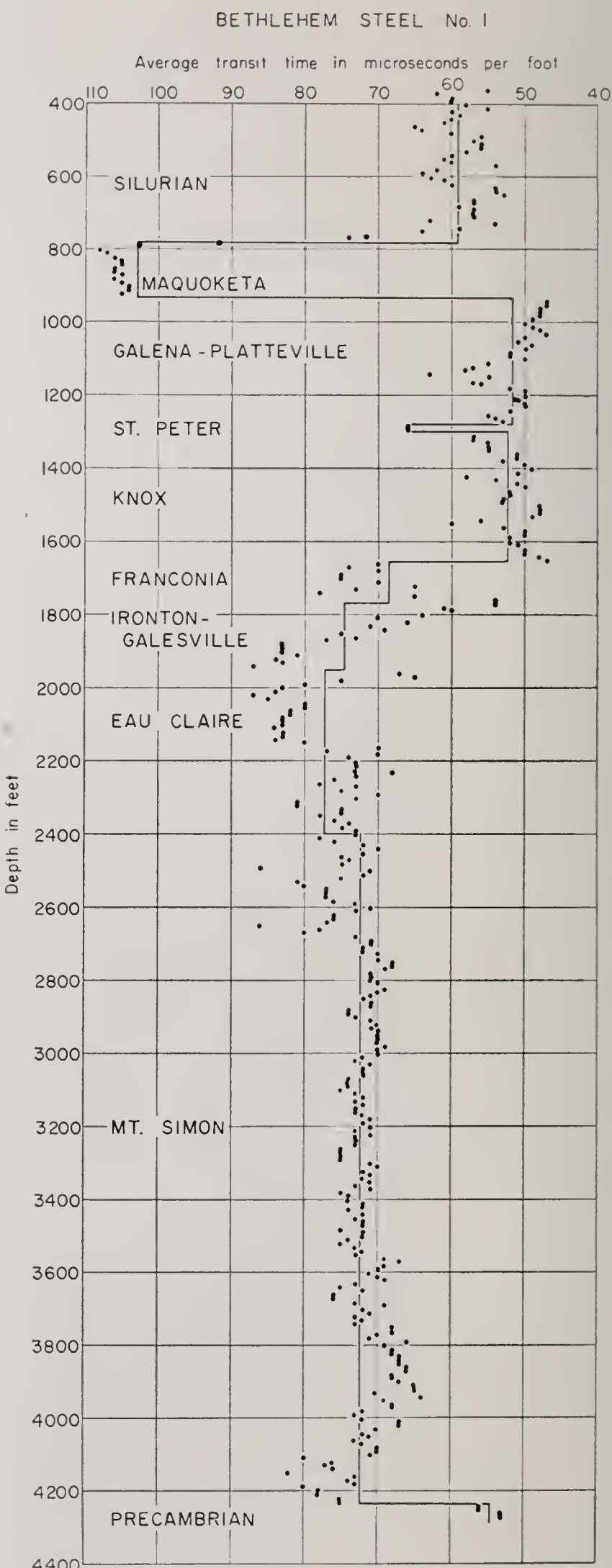


FIG. 9—Average transit time of 10-foot thickness intervals and of stratigraphic units in Bethlehem Steel No. 1 Fee, sec. 28, T. 37 N., R. 6 W., Porter County, Indiana, derived from the sonic log.

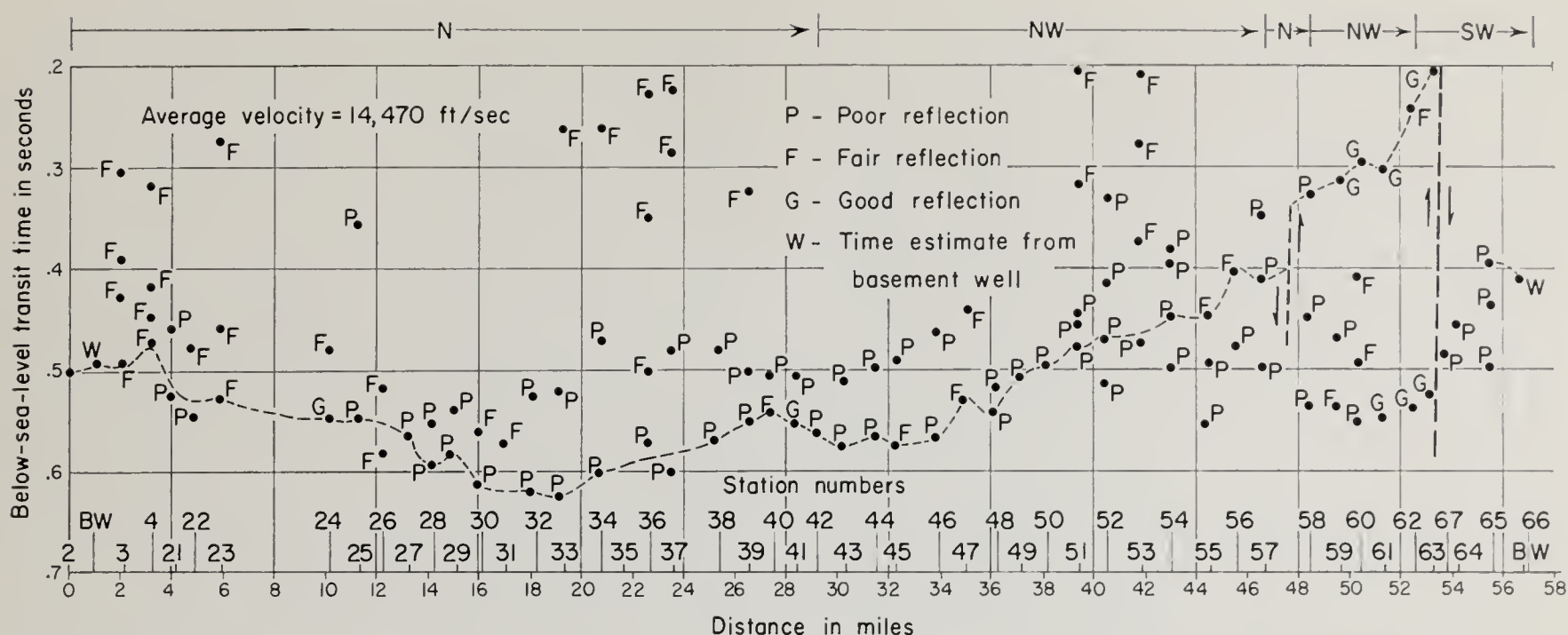


FIG. 10—Corrected reflection times on the seismic traverse in northeastern Illinois. The apparent horst is the result of the angular path of the traverse, which crosses a single proposed fault line twice.

wood-St. Peter; high-density Knox and low-density Franconia; and low-density Mt. Simon and high-density Precambrian basement. Where these contacts are unconformable, especially at the base of the St. Peter and the base of the Mt. Simon, gravity anomalies may be related to the configuration of the unconformable surface, which for analysis of structure is undesirable.

Seismic Interpretation

A 57-mile seismic reflection profile, for which stations were located at about 1-mile intervals, was made between the Reed No. 1 McCoy basement well and the Schulte No. 1 Wyman in sec. 35, T. 41 N., R. 5 E., DeKalb County, to record details of the relief on the basement surface (fig. 13). Other spot reflection stations were occupied in conjunction with shallow refraction surveys. Shot depths ranged from 10 to about 40 feet and charge size (DuPont Nitramon) ranged from 1 to 20 pounds. Reflection quality was generally poor, but an occasional record of good quality was obtained.

For the first part of the profile, four geophones per trace were used; later, eight geophones were found to give better results. However, in areas where reflection quality was good, one geophone per trace would have sufficed. Following a suggestion made by Rudman (1960), we used high frequency filters, but where reflections were good practically any filter setting (other than wide band) could have been used. Use of larger numbers of geophones per trace and higher

filter settings did increase the signal-to-noise ratio in some areas. In other areas reflections could not be obtained with any of the available instruments.

Seismic velocities through the sediments were obtained from a sonic log run in the Bethlehem Steel No. 1 Fee well in northwestern Indiana, about 25 miles from the northeastern Illinois area. The log was continuous from the Silurian to the basement complex, providing the necessary velocity record for deep seismic interpretation. Velocities obtained from two other sonic logs in the area (Northern Illinois Gas Company observation wells in sec. 22, T. 35 N., R. 1 E., and sec. 24, T. 27 N., R. 14 W.) and from refraction shooting compare closely with those of the Bethlehem Steel well. A modification of the Indiana log with average transit times (microseconds per foot) for a 10-foot interval is shown in figure 9. The average bedrock velocity from the bedrock surface to basement was 14,470 feet per second. The correction for glacial drift was based on an average drift velocity of 5500 feet per second.

Times of travel between sea level and a reflecting interface are plotted in figure 10. The letters P, F, and G, denote poor, fair, and good reflection quality, and W indicates the theoretical time calculated from a basement well. Although for the most part the quality is poor, enough good reflections occur to establish a consistent trend for correlation purposes. The record taken at station 41 (sec. 19, T. 39 N., R. 9 E.), centered between the two basement wells, is a good reflection and is reproduced in figure 11.

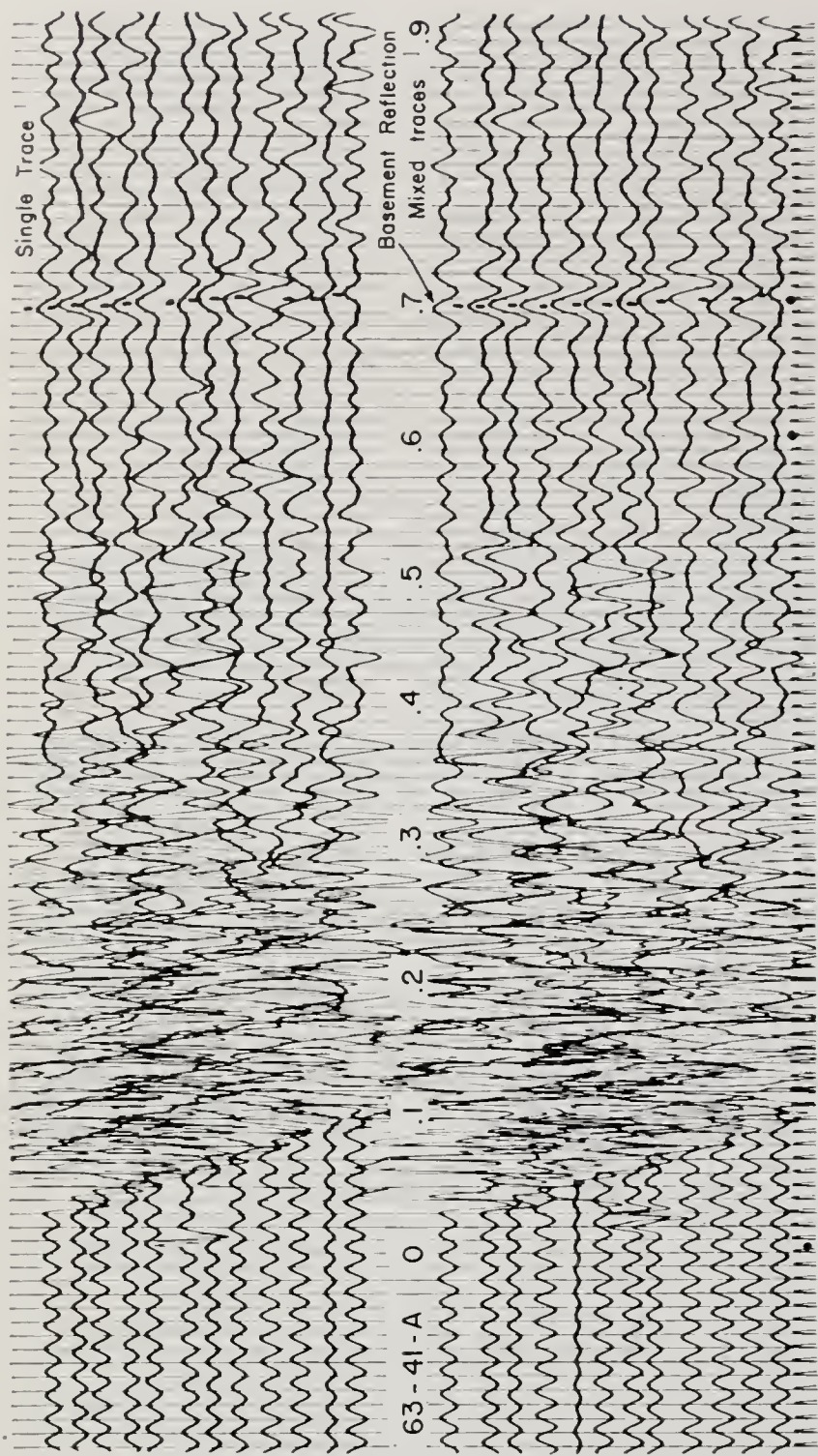


FIG. 11—Seismic reflection record at station 41, sec. 19, T. 39 N., R. 9 E.

The line of short dashes in figure 10 indicates reflections interpreted as being from the basement surface. Transit time increases gradually from south to north to station 33 where the trend reverses and gradually decreases to the northwest to station 57. The quality of the reflections at stations 24, 41, and 63 was good and they were used in correlating the other records with estimated times at the wells near the ends of the profile. Between stations 58 and 63, four good reflections suggest the basement surface is faulted up to the north. Later reflections of good quality also were observed at these stations; however, because three obviously multiple reflections appear on the seismic record in figure 12 (station 63), the late reflections also are assumed to be multiples and the good reflections of least time are believed to represent the basement. Construction of travel paths and observation of reflection

times indicate that the reflection spread was shot with the geophones in the updip direction. The multiples were reflected between basement and the top of the bedrock, which at station 63 is covered by 175 feet of glacial drift. It must be pointed out that the seismic profile is not aligned directly north-south along its entire route. The apparent "horst-like" structure on the profile between stations 57 and 63 is caused by a single fault that is crossed twice by the seismic profile.

Basement Configuration

A basement structure map, based on all available data, is shown in figure 13. In regional features the map differs from Beck's (1965) aeromagnetic interpretation only in the addition of two fault zones, the Sandwich Fault Zone, and one I propose 20 to 30 miles north of the Sandwich Fault. The location and trend of the proposed fault were first interpreted from geological and geophysical data other than the gravity map; later I extended the fault zone eastward along the line of high-gravity gradients.

This interpretation of the configuration of the Precambrian surface in northeastern Illinois differs drastically from earlier interpretations. For comparison, an interpretation (Buschbach, 1964) made by extrapolation from shallow structures and with no geophysical control appears in figure 14. The differences are obvious, with the geophysical interpretation suggesting a much more complex geologic history for northeastern Illinois than can be recognized from geologic study of shallow well records. A graben more than 1000 feet deep in places lies near the crest of the Kankakee Arch roughly paralleling the axis of that major structure. Structural highs occur adjacent to the graben, both to the north and south. A major deviation from earlier interpretations is the structural low extending into extreme northeastern Illinois. This low indicates that extreme northeastern Illinois structurally lies within the Michigan Basin rather than the Illinois Basin.

The structure of the top of the basement and the overlying sediments along the line A-A' on the basement structure map are shown in figure 15. The profile includes two basement wells as primary control points and extends from the high to the south across the graben to the structural high in the north.

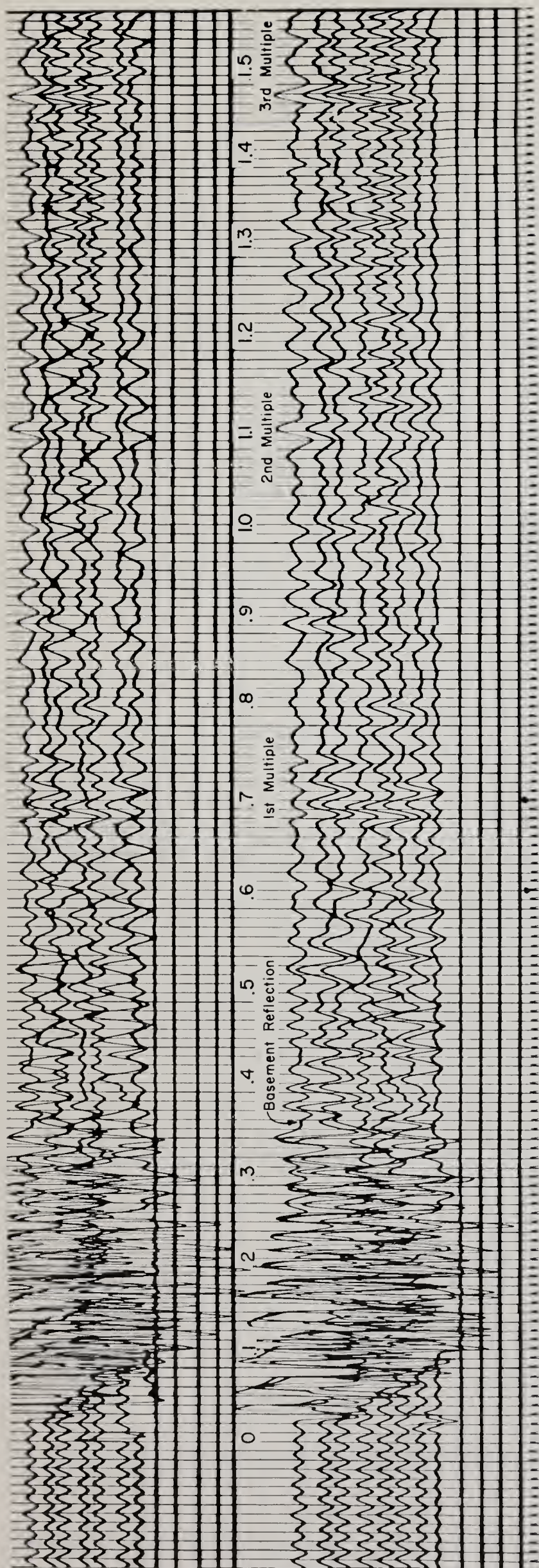


FIG. 12—Seismic reflection record at station 63, sec. 20, T. 41 N., R. 6 E., exhibiting three multiple reflections. This record was shot with 16 pounds of Nitramon at a depth of 30 feet. High filter settings were used with eight geophones per trace on the top bank; lower bank of traces is mixed.

The proposed fault zone on this profile has nearly twice the throw of the Sandwich Fault Zone but is not reflected in the structure of the Glenwood (Middle Ordovician) Sandstone. The Ironton Sandstone (Upper Cambrian), however, sags about 200 feet over the fault zone, which would suggest that movement along this fault continued into late Cambrian time but ceased before middle Ordovician time. The great thickness of late Cambrian sandstones below the Knox Megagroup indicates a sedimentary response to rapid crustal movements involved in the development of the sag.

The Sandwich Fault Zone was formed at an entirely different time than the proposed northern fault. The throw of the basement in the Sandwich Fault Zone is about the same as the throw on the Glenwood Sandstone, indicating that all movement along the Sandwich Fault Zone probably occurred after Glenwood deposition. Evidence at other places suggests that the movement on the Sandwich Fault was post-Silurian. Movement along the suggested fault zone had ceased long before fracturing of the Sandwich Fault Zone began and is probably related to the sinking of the graben area, whereas movements in the Sandwich Fault Zone are related to deepening of the Illinois Basin. The profile of the basement along A-A' (fig. 16) during late Cambrian time can be reconstructed by using the Ironton Sandstone as a reference datum and assuming that its surface was horizontal at the end of Ironton time. This profile illustrates how movement along the northern fault had been completed before Sandwich Fault movement had begun.

Gravity and magnetic profiles also are shown over the graben (fig. 15). The Bouguer gravity field is characterized by a 25-milligal high over the graben, whereas the aeromagnetic profile bears little resemblance to either basement structure or to the gravity profile. However, Bouguer gravity highs generally correlate with magnetic highs in the graben to the east of this profile. Sharp magnetic highs and lows a few miles wide correlate more favorably with the residual gravity profile (fig. 15).

The position of relatively low magnetic and gravity fields over structural highs could only mean that structurally high areas are deficient in magnetite and mass compared to

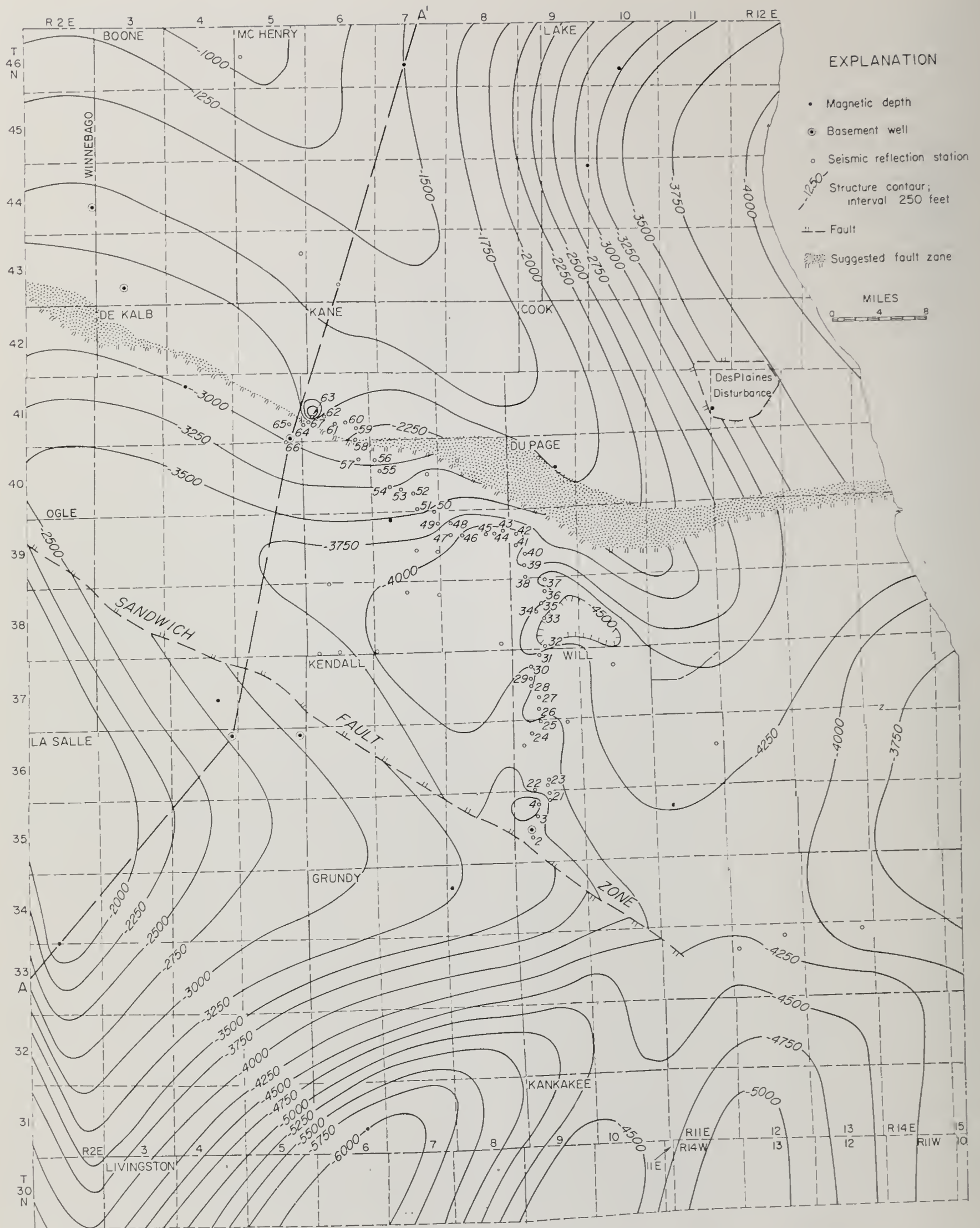


FIG. 13—Precambrian crystalline basement structure in northeastern Illinois based on bore holes and geophysical data.

structurally low areas. If so, the crust beneath the graben is more basic and massive than the surrounding crust. As two basement wells have been drilled into the graben area in northeastern Illinois and encountered red granitic rocks of practically identical description to those of the surrounding region, either

the more basic rocks lie below the granites or the physical difference between the two types of granite is so slight as to be unnoticeable in the mineralogical studies. The latter alternative is preferred here.

The boundaries of the graben, the Sandwich Fault Zone to the southwest and the

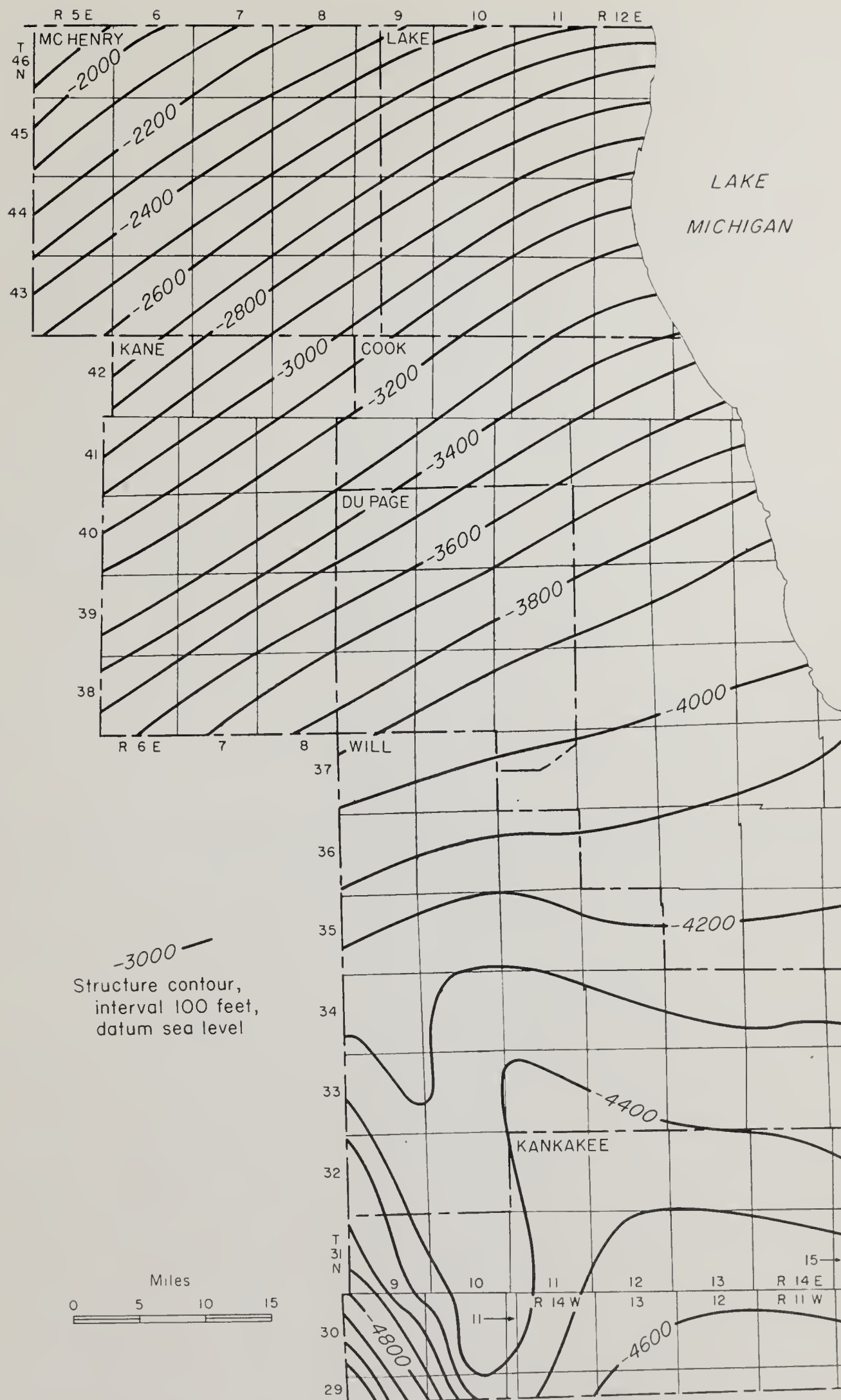


FIG. 14—Precambrian crystalline basement structure in northeastern Illinois based on extrapolation from shallow structures from Buschbach (1964, fig. 6).

inferred basement fault zone to the northeast, are associated with small, high-intensity gravity and magnetic anomalies that indicate intrusive activity along the fault zones. The origin of the graben may be due to tensional stresses produced when an originally plane crust was isostatically undulated, which re-

sulted in fracturing and slippage along heterogeneities. Heiskanen and Vening Meinesz (1958, p. 390) described faulting and graben development caused by tensional stress. They found that tensional stresses may cause crustal blocks 65 km (~41 miles) wide to settle independently to isostatic equilibrium.

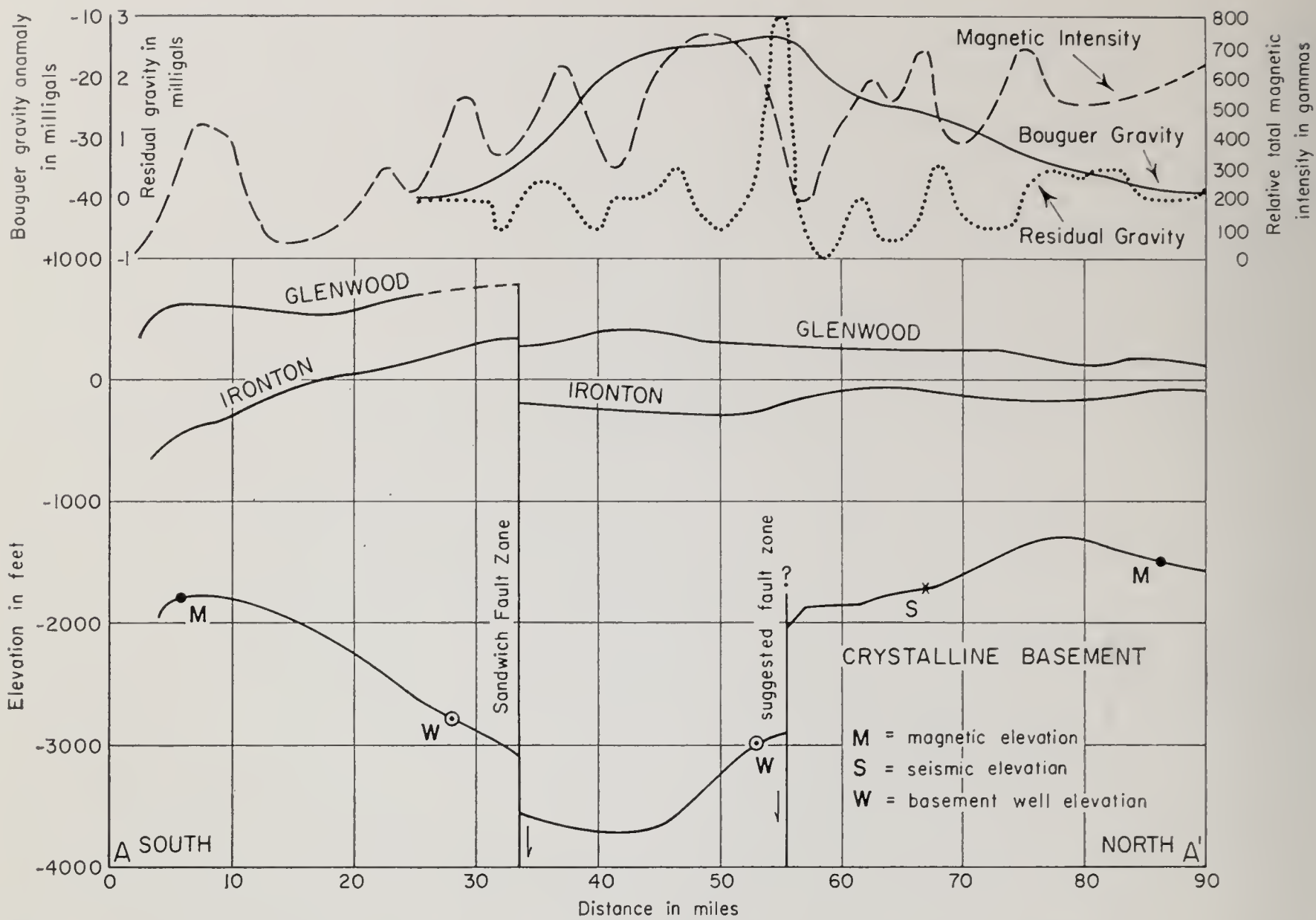


FIG. 15—A profile along line A-A' (fig. 13) showing the structure of the top of the basement and of the overlying sediments in relation to the gravity and magnetic fields. A major unconformity lies at the base of the St. Peter Sandstone between the Glenwood and Ironton Formations.

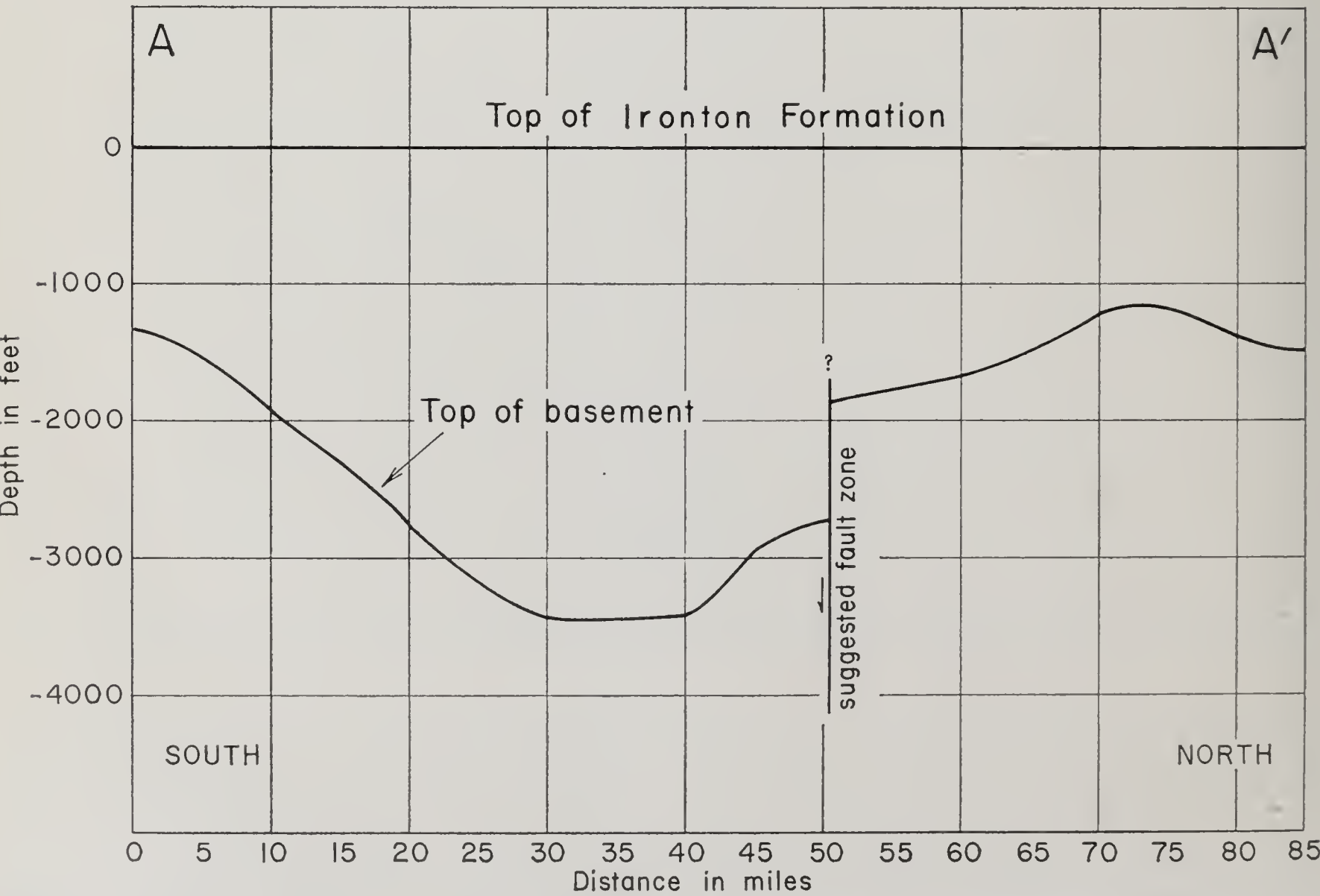


FIG. 16—Profile of basement structure across the graben area at the culmination of Ironton deposition. Location of A-A' is shown in figure 13.

The DesPlaines Disturbance

To illustrate the minimum size of areas that could be involved in differential upward and downward movements caused by tension, with resultant faulting and isostatic adjustments, a brief re-examination of the interpretations (Pemberton, 1954; Emrich and Bergstrom, 1962) of the geology and gravity field associated with the DesPlaines Disturbance in northeastern Illinois is useful. The disturbance, located in T. 41 N., R. 12 E., and covering about 25 square miles, has been given two differing interpretations. Pemberton, to account for an 8-milligal residual gravity low over the disturbance, postulated a basement graben 5000 feet deep filled with low-density sandstone. Emrich and Bergstrom showed from a subsurface study of the stratigraphy in deep wells that this interpretation is untenable. Stratigraphic correlations indicate an over-all uplift of the area.

The seemingly contradictory evidence indicated by the negative anomaly and the obvious upward movement of the sediments can be reconciled if the crystalline rocks beneath the disturbance were originally of low density. Tensional forces caused by the subsiding Michigan and Illinois Basins could have fractured the crust sufficiently to allow isostatic compensation.

PRECAMBRIAN GRAVITY FIELD

If the gravity effects of Paleozoic sediments and structures were eliminated, the gravity field in northeastern Illinois would be that which existed at a time prior to original sediment deposition, assuming no recrystallization of the crust or mantle had occurred. The gravity field in the graben region of northeastern Illinois, as it probably existed during the time just prior to late Cambrian deposition, can therefore be reconstructed.

If the present downfaulting is assumed to average 1000 feet, a slab of low-density (2.44 gm/cc) sandstone would now rest in a high-density (2.62 gm/cc) crystalline trough. Instead of the gravity low of -2.3 milligals that was expected to be associated with this trough, a gravity high of $+20$ milligals was measured. Thus, the actual anomaly existing today is opposite in sign and is much greater than the anomaly calculated for the assumed condition of sandstone fill of the graben. This

leads to the conclusion that, before faulting, the mass distribution of the crust must have been such that the amplitude of the Bouguer anomaly was greater than that now observed.

If the crust can be considered to be a thin, floating, heterogeneous membrane, the width of complete compensation will vary, depending on the physical properties of the membrane and the stresses acting upon it. Thus, for a crust of heterogeneous nature, as depicted by the gravity map, that is undergoing tensional stress, very small areas could be involved in isostatic adjustments. If the density distribution existing over the graben in northeastern Illinois during Precambrian time was similar to that of today (fig. 17A), the central axis of the Kankakee Arch would have had a tendency to subside, whereas the average density for the entire Kankakee Arch would give the arch a tendency to remain rather stationary. If the masses on the arch were allowed to come to complete isostatic equilibrium, the high Bouguer anomaly area would subside in relation to the lower Bouguer anomaly area (fig. 17B) until compensation was complete. At this point, although the graben would have been in isostatic equilibrium, the development of relief would result in the ultimate filling of the graben with sediment (fig. 17C). The trough that had once been adjusted (fig. 17B) would again be uncompensated due to the filling-in of sediment, and a new Bouguer anomaly high would be created. The amplitude of the new anomaly would depend on the amount of compensation, the density, and the thickness of sediment filling the graben. Densities shown in figure 17 for the Precambrian rocks refer only to the upper crust; however, the density contrast is assumed to extend to the base of the crust. A density contrast of $.04 \text{ gm/cm}^3$ (for a crust 35 km thick) between the basement rock below the graben and the surrounding area is sufficient to produce a gravity anomaly having the desired shape and amplitude. The final theoretical gravity anomaly over a graben filled with sandstone is nearly identical to the observed anomaly (fig. 17C). The observed anomaly is taken from a profile drawn at right angles to the gravity high through the southeast corner of sec. 32, T. 41 N., R. 6 E. (pl. 2). The theoretical anomaly for a high-density crust in the graben area is derived by adding the effects of two parallel faults separated from each other by

some distance. The gravity anomaly (g_z) produced by a vertical fault is (Nettleton, 1940, p. 113):

$$g_z = 2 \gamma \sigma t \left[\frac{\pi}{2} - \arctan \left(\frac{x}{z} \right) \right] \quad (5)$$

and this is modified to the gravity field over a graben of infinite elongation so that

$$g_z = -2 \gamma \sigma t \left[\arctan \left(\frac{x}{z} \right) + \arctan \left(-\frac{x+w}{z} \right) \right] \quad (6)$$

where γ is the gravitational constant (6.67×10^{-8} cgs), σ is the density contrast, t is the thickness of a slab or throw of a fault, w is the width of the anomalous mass, x is the distance from either fault, and z is the mean depth of the slab.

The base of the downthrown graben, at the depth of isostatic compensation (~ 113 km, according to Nettleton, 1940), would produce a local anomaly of less than half a milligal and is therefore not considered here.

The original crystalline mass causing the Bouguer gravity high shown in figure 17 was caused either by chemical and thermal conditions of the crust at the time it originally crystallized or by Precambrian intrusive or volcanic activity rather than by Paleozoic events. The smaller, very high intensity, circular anomalies found along the fault zones are probably due to intrusions that occurred at the time of faulting. These intrusions would be younger than the rocks causing the broader gravity highs.

Woollard (1962) noted an elongate, positive, free-air anomaly in central Kentucky that is associated with the Cincinnati Arch, although the gravity high is too intense and too narrow to be caused by the arch. He concluded that the gravity high is caused by high-density rocks in the upper crust. It would be of interest to study these other gravity highs on the arches surrounding the

Illinois Basin to see whether they are associated with grabens.

A situation comparable to that described above is the Bouguer gravity anomaly high associated with the Red Sea Rift. Drake and Girdler (1964) have described the Red Sea Rift as a down-dropped block that formed as a result of tension. Both free-air and Bouguer gravity anomalies indicate the rift is a gravity high relative to the shores of the Red Sea.

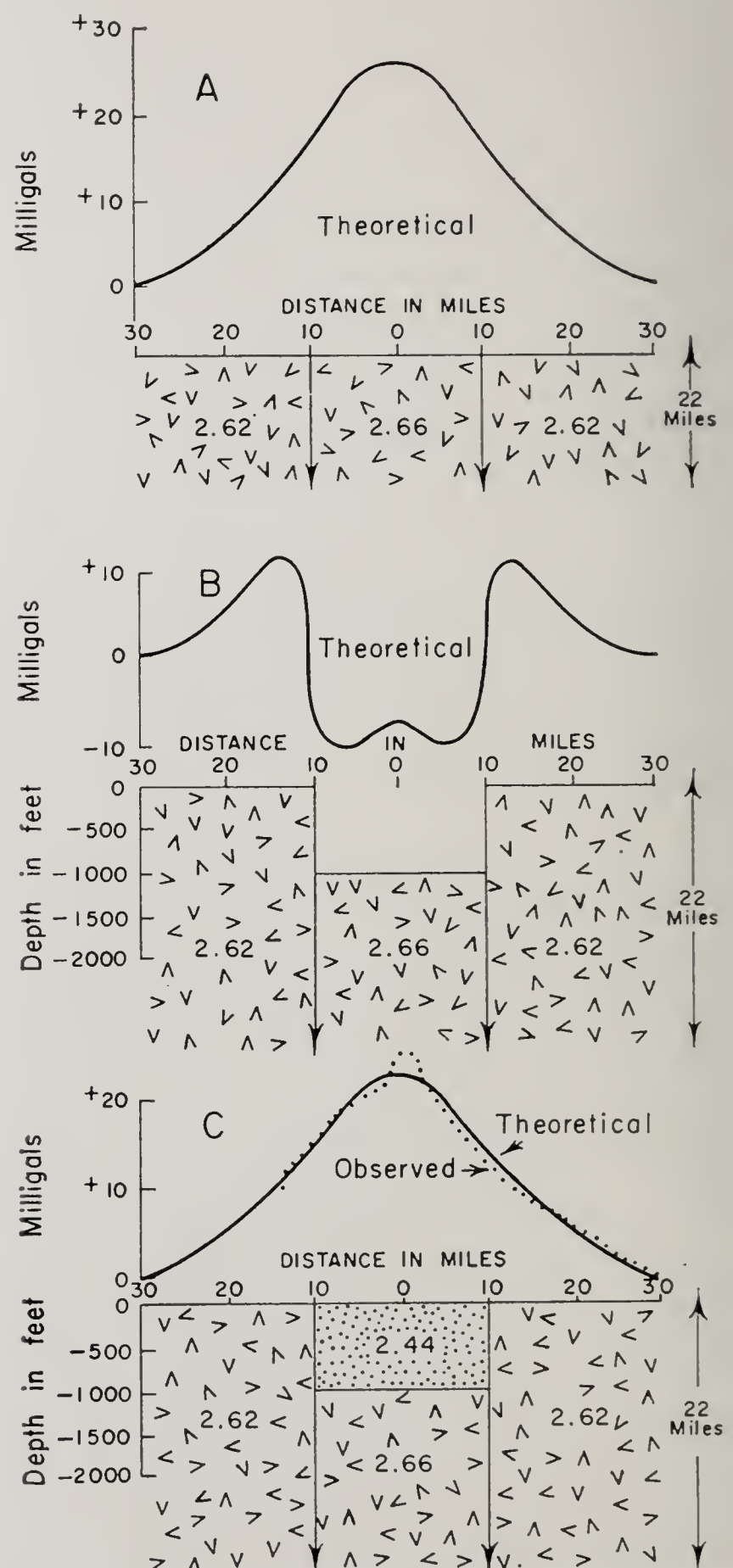


FIG. 17—Reconstruction of the gravity field over the graben in northeastern Illinois. (A) Gravity field caused by a simple density contrast in the crust. (B) Gravity field over the graben without sediment. (C) Comparison of theoretical and observed gravity fields over the graben filled with sandstone.

SUMMARY AND CONCLUSIONS

Geophysical potential fields aid not only in defining the present geologic framework but also in providing clues to geologic processes that have produced the framework. An understanding of these processes permits a more thorough approach to the analysis of the present geologic setting.

Deep bedrock structures in the central United States can be inferred from the apparent inverse relation between the Bouguer gravity field and basement structure. Crustal density contrasts sufficient to produce anomalies of 30 to 40 milligals have resulted in such structures as the broad basins and arches found in the craton in the Midwest.

A basement fault zone, north of and roughly parallel to the Sandwich Fault Zone, has been proposed, based on all available geophysical data. The graben formed between

the two fault zones is filled with relatively low-density Mt. Simon Sandstone of late Cambrian age. Movement along the proposed fault ceased before middle Ordovician time, whereas movement on the Sandwich Fault was post-Silurian. Displacement along the proposed fault was caused by subsidence of a high-density crustal block between the two faults. Displacement along the Sandwich Fault Zone was due to subsidence of the Illinois Basin.

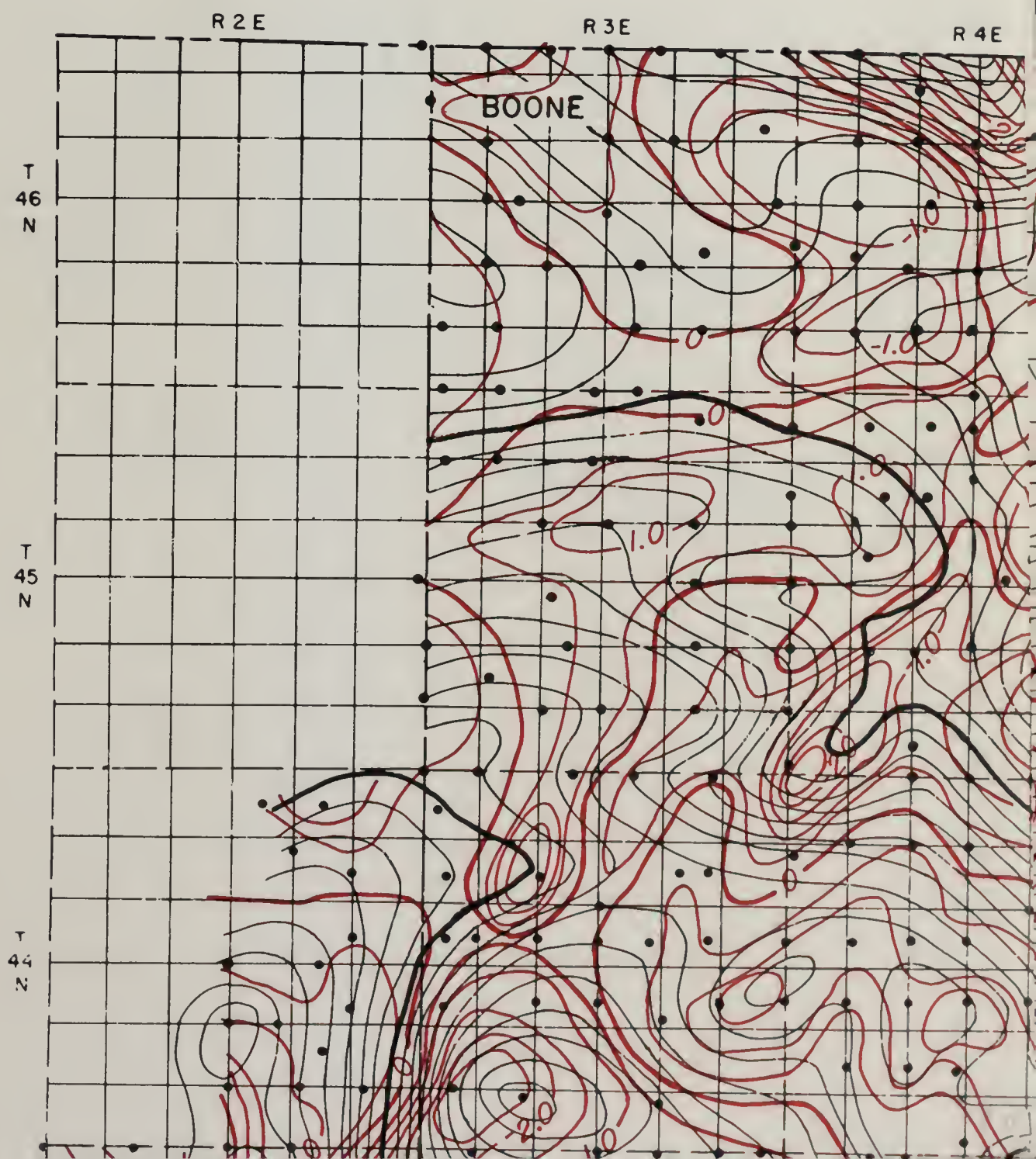
In northeastern Illinois small structures also are shown to be inversely related to Bouguer gravity anomalies. The reason for this relation is that the northeastern Illinois region contains a heterogeneous crust. Tensional stresses, due to an undulating crust, have resulted in faulting followed by local isostatic compensation. Both uplift and subsidence of small crustal blocks have occurred.

REFERENCES

- ALGER, R. P., RAYMER, L. L., HOYLE, W. R., and TIXIER, M. P., 1963, Formation density log applications in liquid-filled holes: *Jour. Petroleum Technology*, v. 15, no. 3, p. 321-332.
- BECK, M. E., JR., 1965, Aeromagnetic map of northeastern Illinois and its geologic interpretation: *U.S. Geol. Survey Geophys. Inv. Map GP-523*.
- BEHRENDT, J. S., and WOOLLARD, G. P., 1961, An evaluation of the gravity control network in North America: *Geophysics*, v. 26, no. 1, p. 57-76.
- BELL, A. H., ATHERTON, ELWOOD, BUSCHBACH, T. C., and SWANN, D. H., 1964, Deep oil possibilities of the Illinois Basin: *Illinois Geol. Survey Circ.* 368, 38 p.
- BUSCHBACH, T. C., 1964, Cambrian and Ordovician strata of northeastern Illinois: *Illinois Geol. Survey Rept. Inv.* 218, 90 p.
- CADY, G. H., 1920, The structure of the LaSalle Anticline: *Illinois Geol. Survey Bull.* 36, p. 85-179.
- COHEE, G. V., et al., 1961, Tectonic map of the United States: *U.S. Geol. Survey and Am. Assoc. Petroleum Geologists*.
- COONS, R. L., MACK, J. W., and STRANGE, WILLIAM, 1964, Least-square polynomial fitting of gravity data and case histories, in G. A. Parks, ed., *Computers in the mineral industries: School of Earth Sci., Stanford Univ.*, p. 498-519.
- DRAKE, C. L., and GIRDLER, R. W., 1964, A geophysical study of the Red Sea: *Geophys. Jour. Royal Astron. Soc.*, v. 8, no. 5, p. 473-495.
- EKBLAW, GEORGE E., 1938, Kankakee Arch in Illinois: *Geol. Soc. America Bull.*, v. 49, p. 1425-1430.
- EMRICH, G. H., and BERGSTROM, R. E., 1962, Des Plaines Disturbance, northeastern Illinois: *Geol. Soc. America Bull.*, v. 73, p. 959-968.
- HEIGOLD, P. C., MCGINNIS, L. D., and HOWARD, R. H., 1964, Geologic significance of the gravity field in the DeWitt-McLean County area, Illinois: *Illinois Geol. Survey Circ.* 369, 16 p.
- HEISKANEN, W. A., and VENING MEINESZ, F. A., 1958, *The earth and its gravity field*: McGraw-Hill Book Co., Inc., New York, 470 p.
- HENDERSON, J. R., and ZIETZ, ISIDORE, 1958, Interpretation of an aeromagnetic survey of Indiana: *U.S. Geol. Survey Prof. Paper* 316-B, 37 p.
- HINZE, W. J., 1963, Regional gravity and magnetic anomaly maps of the southern peninsula of Michigan: *Michigan Dept. Conserv., Michigan Geol. Survey Rept. Inv.* 1, 26 p.
- KEMPTON, J. P., 1962, Stratigraphy of the glacial deposits in and adjacent to the Troy Bedrock Valley, northern Illinois: *Univ. Illinois [Urbana]* unpublished Ph.D. thesis, 129 p.
- LYONS, P. L., 1959, The Greenleaf anomaly, a significant gravity feature: *Kansas Geol. Survey Bull.* 137, p. 105-120.
- MACK, J. W., 1963, A least-square method of gravity analysis and its application in the study of sub-surface geology: *Univ. Wisconsin [Madison]* unpublished Ph.D. thesis, 122 p.
- MCGINNIS, L. D., 1965, Crustal movements in northeastern Illinois: *Univ. Illinois [Urbana]* unpublished Ph.D. thesis, 155 p.
- MCGINNIS, L. D., and HEIGOLD, P. C., 1961, Regional maps of vertical magnetic intensity in Illinois: *Illinois Geol. Survey Circ.* 324, 12 p.
- MCGINNIS, L. D., KEMPTON, J. P., and HEIGOLD, P. C., 1963, Relationship of gravity anomalies to a drift-filled bedrock valley system in northern Illinois: *Illinois Geol. Survey Circ.* 354, 23 p.
- NETTLETON, L. L., 1940, *Geophysical prospecting for oil*: McGraw-Hill Book Co., Inc., New York, 444 p.
- PEMBERTON, R. H., 1954, Gravity survey of the Des Plaines complex, Cook County, Illinois: *Univ. Wisconsin [Madison]* unpublished M.S. thesis, 62 p.
- RAMBERG, HANS, and STEPHANSSON, OVE, 1964, Compression of floating elastic and viscous plates affected by gravity, a basis for discussing crustal buckling: *Tectonophysics*, v. 1, no. 1, p. 101-120.
- RUDMAN, A. J., 1960, A seismic reflection survey of the surface of the basement complex in Indiana: *Indiana Dept. Conserv., Indiana Geol. Survey Rept. Prog.* 18, 26 p.
- STEINHART, J. S., and MEYER, R. P., 1961, Explosion studies of continental structure: *Carnegie Inst. Pub.* 622, Washington, D.C., 409 p.
- SUTER, MAX, BERGSTROM, R. E., SMITH, H. F., EMRICH, G. H., WALTON, W. C., and LARSON, T. E., 1959, Preliminary report on groundwater resources of the Chicago region, Illinois: *Illinois Water Survey and Illinois Geol. Survey Coop. Ground-Water Rept.* 1, 89 p.
- THIEL, E. C., 1956, Correlation of gravity anomalies with the Keweenawan geology of Wisconsin and Minnesota: *Geol. Soc. America Bull.*, v. 67, p. 1079-1100.
- THWAITES, F. T., 1927, Stratigraphy and geologic structure of northern Illinois with special reference to underground water supplies: *Illinois Geol. Survey Rept. Inv.* 13, 49 p.

- WILLMAN, H. B., and PAYNE, J. N., 1942, Geology and mineral resources of the Marseilles, Ottawa, and Streator Quadrangles: Illinois Geol. Survey Bull. 66, 388 p.
- WILLMAN, H. B., and TEMPLETON, J. S., 1951, Cambrian and lower Ordovician exposures in northern Illinois: Illinois Acad. Sci. Trans., v. 44, p. 109-125. (Reprinted in Illinois Geol. Survey Circ. 179, 1952, 16 p.)
- WOOLLARD, G. P., 1962, The determination of gravity from elevation and geologic data: Univ. Wisconsin Geophys. and Polar Research Center, Research Rept. Ser. 62-9, 256 p.
- WOOLLARD, G. P., and JOESTING, H. R., 1964, Bouguer gravity anomaly map of the United States: Am. Geophysical Union and U.S. Geol. Survey.
-

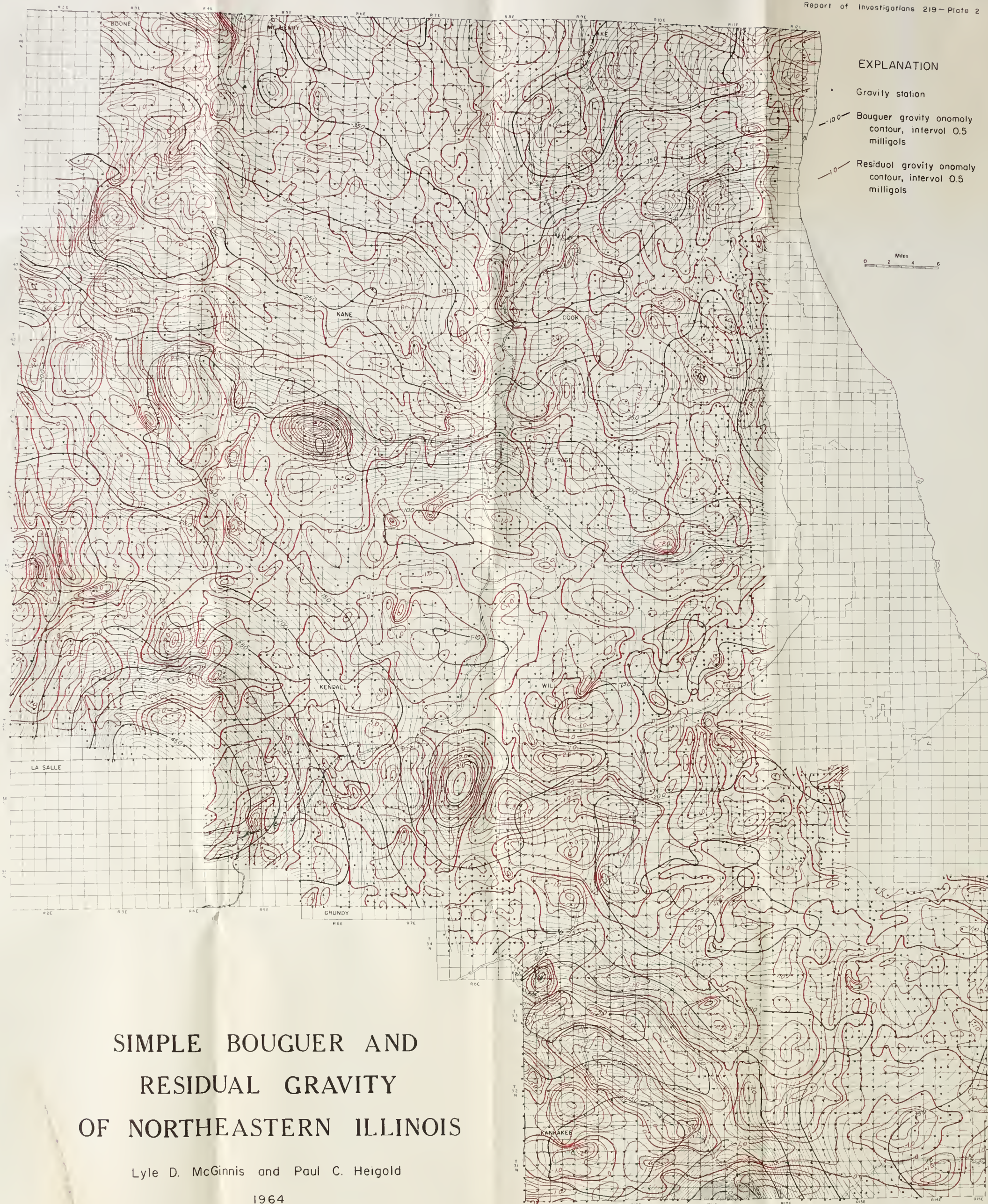
Illinois State Geological Survey



EXPLANATION

- Gravity station
- 100— Bouguer gravity anomaly contour, interval 0.5 milligals
- 10— Residual gravity anomaly contour, interval 0.5 milligals

Miles
0 2 4 6



SIMPLE BOUGUER AND RESIDUAL GRAVITY OF NORTHEASTERN ILLINOIS

Lyle D. McGinnis and Paul C. Heigold

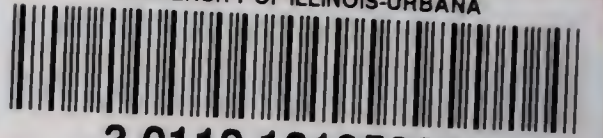
1964

I557.73

Gr-219

c.3

UNIVERSITY OF ILLINOIS-URBANA



3 0112 121958893